Washington State
Department of Transportation

Interstate 5 MP 240.92 and 240.95
South Unnamed Tributary to Friday Creek
(WDFW IDs: 995236, 995235, 995234, 995233, 995232, and 995245)

Preliminary Hydraulic Design Report

Julie Heilman, PE (FPT20-00157)
State Hydraulic Engineer
WSDOT Headquarters Hydraulic Office

Ryan Makie, PE, Stream Design Engineer (FPT20-04646)
Otak, Inc.

Jennifer Goldsmith, LG, Geomorphologist (FPT20-08489)
Otak, Inc.

Norton Posey, PE, Project Manager (FPT20-16365)
Otak, Inc.

Americans with Disabilities Act (ADA) Information

Materials can be made available in an alternative format by emailing the Washington State Department of Transportation (WSDOT) Diversity/ADA Affairs Team at wsdotada@wsdot.wa.gov or by calling toll free: 855-362-4ADA (4232). Persons who are deaf or hard of hearing may contact that number via the Washington Relay Service at 7-1-1.

Title VI Notice to Public

It is WSDOT policy to ensure no person shall, on the grounds of race, color, national origin, or sex, as provided by Title VI of the Civil Rights Act of 1964, be excluded from participation in, be denied the benefits of, or be otherwise discriminated against under any of its federally funded programs and activities. Any person who believes his/her Title VI protection has been violated may file a complaint with WSDOT's Office of Equal Opportunity (OEO). For Title VI complaint forms and advice, please contact OEO's Title VI Coordinator at 360-705-7082 or 509-324-6018.

Contents

1 Introduction 1
2 Watershed and Site Assessment 5
2.1 Watershed and Land Cover 5
2.2 Geology and Soils 10
2.3 Floodplains 13
2.4 Site Description 13
2.5 Fish Presence in the Project Area 16
2.6 Wildlife Connectivity 19
2.7 Site Assessment 19
2.7.1 Data Collection 20
2.7.2 Existing Conditions 23
2.7.3 Fish Habitat Character and Quality 37
2.8 Geomorphology 39
2.8.1 Reference and Design Reach Selection 39
2.8.2 Channel Geometry 46
2.8.3 Sediment 61
2.8.4 Vertical Channel Stability 71
2.8.5 Channel Migration 76
2.8.6 Riparian Conditions, Large Wood, Other Habitat Features 77
3 Hydrology and Peak Flow Estimates 82
4 Hydraulic Analysis and Design 85
4.1 Model Development 85
4.1.1 Topographic and Bathymetric Data 85
4.1.2 Model Extent and Computational Mesh 85
4.1.3 Materials/Roughness 96
4.1.4 Boundary Conditions 103
4.1.5 Model Run Controls 117
4.1.6 Model Assumptions and Limitations 117
4.2 Existing Conditions Model Results 117
4.3 Natural Conditions 133
4.4 Channel Design 144
4.4.1 Floodplain Utilization Ratio 144
4.4.2 Channel Planform and Shape 144
4.4.3 Channel Alignment 150

4.4.4 Channel Gradient 153
4.5 Design Methodology 156
4.6 Future Conditions – Proposed Minimum Hydraulic Openings....................................157
4.6.1 Proposed Reach A 157
4.6.2 Proposed Reach B 158
4.7 Water Crossing Design 180
4.7.1 Structure Type..180
4.7.2 Minimum Hydraulic Opening Width and Length..180
4.7.3 Freeboard 182
5 Streambed Design..185
5.1 Bed Material..185
5.1.1 Site Constraints..185
5.1.2 Streambed Material Decision Tree 185
5.1.3 Proposed Streambed Sediment Sizing..186
5.1.4 Step-Pools 191
5.1.5 Meander Bars..194
5.2 Channel Complexity..195
5.2.1 Design Concept..195
5.2.2 Additional Items for Further Design 201
6 Floodplain Changes 202
6.1 Floodplain Storage..202
6.2 Water Surface Elevations..202
7 Climate Resilience..204
7.1 Climate Resilience Tools..204
7.2 Hydrology..204
7.3 Climate Resilience Summary 204
8 Scour Analysis 205
8.1 Lateral Migration 205
8.2 Long-Term Aggradation/Degradation of the Channel Bed....................................206
8.2.1 Existing Conditions..206
8.2.2 Proposed Conditions..207
8.2.3 Proposed Reach A 207
8.2.4 Proposed Reach B 208
9 Summary..210
10 References..212
11 Appendices 216

Figures

Figure 1: Vicinity Map....3
Figure 2: South Tributary Culverts in the Vicinity of I-5/Lake Samish Road Interchange 4
Figure 3: South Tributary Drainage Basin (based on 2016 LiDAR)....6
Figure 4: South Tributary Relief Map (based on 2016 LiDAR)....7
Figure 5: Land Use in the Vicinity of the South Tributary Project Area 8
Figure 6: Historical Aerial Image of South Tributary Watershed from 1981 9
Figure 7: Surficial Geology Map in the Vicinity of the South Tributary Project Area (based on Lapen 2000) 11
Figure 8: Soils in the Vicinity of the South Tributary Project Area....12
Figure 9: South Tributary Field Data Collection Locations....22
Figure 10: Culvert 995236 Inlet....23
Figure 11: Culvert 995236 Outlet 24
Figure 12: Culvert 995235 Inlet....26
Figure 13: Culvert 995235 Outlet 26
Figure 14: Culvert 995234 Inlet (and Culvert 995235 Outlet)....27
Figure 15: Culvert 995234 Outlet 28
Figure 16: Culvert 995233 Inlet....29
Figure 17: Culvert 995233 Outlet (and Culvert 995232 Outlet) with Deposition....30
Figure 18: Culvert 995233 Outlet (and Culvert 995232 Outlet) showing a Water Surface Drop and no Deposition (photo taken in 2011 by WDFW) 30
Figure 19: Culvert 995232 Inlet (and Culvert 995233 Outlet)....32
Figure 20: Culvert 995232 Outlet 32
Figure 21: Culvert 995232 Outlet showing Sediment Deposition and Submerged Culvert Conditions (photo taken in 2011 by WDFW)....33
Figure 22: Culvert 995245 Inlet....34
Figure 23: Culvert 995245 Outlet 35
Figure 24: Inlet of Culvert near I-5 MP 240.86....36
Figure 25: Outlet of Culvert near I-5 MP 240.86....36
Figure 26: South Tributary Upstream Reference Reach and Downstream Design Reach Locations....40
Figure 27: View of the South Tributary Reference Reach Located Upstream of Culvert 995236, Looking Upstream (west)....41
Figure 28: Typical Reference Reach Channel Morphology, View Looking Upstream (west)....42
Figure 29: Typical Step-Pool Within Upstream Reference Reach....43

Figure 30: View of the South Tributary Downstream of I-5 along Barleen Road, Looking Downstream (east) 44
Figure 31: South Tributary Design Reach Downstream of Barleen Road Culvert (931905) 44
Figure 32: Measurement Locations 47
Figure 33: South Tributary Reference Reach Existing Cross Sections 48
Figure 34: South Tributary Existing Cross Sections (in Project Reach and Downstream Reach) 49
Figure 35: Bankfull Width #1 50
Figure 36: Bankfull Width #2 51
Figure 37: Bankfull Width #3 51
Figure 38: Reference Reach Bankfull Width #4, Looking Upstream 52
Figure 39: Reference Reach near Bankfull Width #4, Looking Downstream 52
Figure 40: Bankfull Width #5 53
Figure 41: Bankfull Width #6 53
Figure 42: Bankfull Width #7 54
Figure 43: Bankfull Width #8, View Looking Upstream 55
Figure 44: Bankfull Width #9 Between Culverts 995232 and 995245 56
Figure 45: Bankfull Width #10 57
Figure 46: South Tributary in Downstream Reach East of I-5, View Looking Downstream 58
Figure 47: Bankfull Width #12, Within Downstream Design Reach 59
Figure 48: Bankfull Width #13, Within Downstream Design Reach 60
Figure 49: Bankfull Width #14, Within Downstream Design Reach 60
Figure 50: Pebble Count #1 62
Figure 51: South Tributary Reference Reach Pebble Count #1 63
Figure 52: Pebble Count #2 63
Figure 53: South Tributary Reference Reach Pebble Count #2 64
Figure 54: Pebble Count #3 64
Figure 55: South Tributary Reference Reach Pebble Count #3 65
Figure 56: South Tributary Reference Reach Pebble Count Gradation 66
Figure 57: South Tributary Reference Reach Large Boulder 67
Figure 58: South Tributary Reference Reach Large Boulder 67
Figure 59: Pebble Count #4 68
Figure 60: Pebble Count #5 68
Figure 61: South Tributary Downstream Reach Pebble Count Gradation 69
Figure 62: Pebble Count #6 70
Figure 63: South Tributary Downstream Design Reach Pebble Count #6 70
Figure 64: Substrate Gradation Within the Downstream Design Reach 71

Figure 65: South Tributary Watershed Scale Longitudinal Profile....74
Figure 66: Stream Profile through I-5/Lake Samish Interchange (Project Reach)....75
Figure 67: Channel Incision in the Reference Reach....76
Figure 68: Vegetation Conditions in the South Tributary Reference Reach....78
Figure 69: Vegetation Conditions at the I-5 Interchange....79
Figure 70: Vegetation Conditions in the South Tributary Downstream Reach Adjacent to Barleen Road....80
Figure 71: Vegetation Conditions in the South Tributary Downstream of Barleen Road (Design Reach)....81
Figure 72: Existing Conditions Computational Mesh with Underlying Terrain (overall)....87
Figure 73: Existing Conditions Computational Mesh with Underlying Terrain (upstream)....88
Figure 74: Existing Conditions Computational Mesh with Underlying Terrain (downstream)....89
Figure 75: Natural Conditions Computational Mesh with Underlying Terrain (overall)....90
Figure 76: Natural Conditions Computational Mesh with Underlying Terrain (upstream)....91
Figure 77: Natural Conditions Computational Mesh with Underlying Terrain (downstream)....92
Figure 78: Proposed Conditions Computational Mesh with Underlying Terrain (overall)....93
Figure 79: Proposed Conditions Computational Mesh with Underlying Terrain (upstream)....94
Figure 80: Proposed Conditions Computational Mesh with Underlying Terrain (downstream)....95
Figure 81: Spatial Distribution of Roughness Values in the Existing Conditions Model....100
Figure 82: Spatial Distribution of Roughness Values in the Natural Conditions Model....101
Figure 83: Spatial Distribution of Roughness Values in the Proposed Conditions Model....102
Figure 84: South Tributary Existing Conditions Model Boundary Conditions....105
Figure 85: Input Data for HY-8 Boundary Condition Arcs at Culvert 995236....106
Figure 86: Input Data for HY-8 Boundary Condition Arcs at Culvert 995235....106
Figure 87: Input Data for HY-8 Boundary Condition Arcs at Culvert 995234....107
Figure 88: Input Data for HY-8 Boundary Condition Arcs at Culvert 995233....107
Figure 89: Input Data for HY-8 Boundary Condition Arcs at Culvert 995232....108
Figure 90: Input Data for HY-8 Boundary Condition Arcs at Culvert 995245....108
Figure 91: Input Data for HY-8 Boundary Condition Arcs at Culvert near MP 240.86....109
Figure 92: South Tributary Natural Conditions Model Boundary Conditions....111
Figure 93: South Tributary Proposed Conditions Model Boundary Conditions....112
Figure 94: Inflow Boundary Conditions Time Series for the South Tributary Inflow under Natural and Proposed Conditions....113
Figure 95: Inflow Boundary Condition Time Series for the Drainage into the Culvert near MP 240.86 under Natural and Proposed Conditions....113
Figure 96: Inflow Boundary Conditions Time Series for the Internal Sink for the Inflow from the Roadway Runoff Under Natural and Proposed Conditions....114

Figure 97: Downstream Normal Depth Boundary Input Data....115
Figure 98: South Tributary Downstream Normal Depth Rating Curve....115
Figure 99: Normal Depth Boundary Condition for North I-5 Roadside Ditch....116
Figure 100: Normal Depth Boundary Condition Rating Curve for North I-5 Roadside Ditch....116
Figure 101: South Tributary Locations of Cross Sections Used for Existing Conditions Results Reporting....119
Figure 102: Longitudinal Profile Stationing for Existing Conditions....120
Figure 103: Existing Conditions Water Surface Profiles (overall)....122
Figure 104: Existing Conditions Water Surface Profiles (upstream)....123
Figure 105: Existing Conditions Water Surface Profiles (downstream)....124
Figure 106: Existing Upstream Channel Cross Section (Sta. 21+58)....125
Figure 107: Existing Upstream Channel Cross Section (Sta. 21+42)....126
Figure 108: Existing Upstream Channel Cross Section (Sta. 21+20)....127
Figure 109: Typical Existing Cross Section Within Median (Sta. 16+31)....128
Figure 110: Typical Existing Downstream Channel Cross Section (Sta. 11+66)....129
Figure 111: Existing Conditions 100-Year Velocity Map with Cross Section Locations....130
Figure 112: Existing Conditions 100-Year Velocity Map with Cross Section Locations (upstream)....131
Figure 113: Existing Conditions 100-Year Velocity Map with Cross Section Locations (downstream)....132
Figure 114: Plan View of Natural Conditions Model Mesh with Cross Section Locations....134
Figure 115: Natural Conditions Model Water Surface Profiles (overall)....135
Figure 116: Natural Conditions Water Surface Profiles (upstream)....136
Figure 117: Natural Conditions Water Surface Profiles (downstream)....137
Figure 118: Typical Natural Conditions Upstream Channel Cross Section (Sta. 21+42)....138
Figure 119: Typical Natural Conditions Cross Section Within Median (Sta. 16+30)....139
Figure 120: Typical Natural Conditions Downstream Cross Section (Sta. 1+92)....140
Figure 121: Natural Conditions 100-Year Velocity Map with Cross Section Locations....141
Figure 122: Natural Conditions 100-Year Velocity Map with Cross Section Locations (upstream)....142
Figure 123: Natural Conditions 100-Year Velocity Map with Cross Section Locations (downstream)....143
Figure 124: South Tributary Existing and Proposed Stream Channel Alignments at the I-5/Lake Samish Road Interchange....145
Figure 125: Comparison of the Proposed Reach A Cross Section to the Typical Upstream Reference Reach Cross Section....149
Figure 126: Typical Cross Section for Reach A....150
Figure 127: Typical Cross Section for Reach B....150

Figure 128: South Tributary Summary of Alternative Alignments 151
Figure 129: Proposed Stream Profile with Slopes and Typical Stream Morphologies 154
Figure 130: Channel Types and Associated Slopes (taken from Montgomery and Buffington 1993) 155
Figure 131: South Tributary Locations of Cross Sections Used for Proposed Conditions Results Reporting 160
Figure 132: Longitudinal Profile Stationing for Proposed Conditions 161
Figure 133: Proposed Conditions 100-Year Velocity Map (overall) 164
Figure 134: Proposed Conditions 100-Year Velocity Map (upstream) 165
Figure 135: Proposed Conditions 100-Year Velocity Map (downstream) 166
Figure 136: Proposed Conditions Water Surface Profiles (overall) 167
Figure 137: Proposed Conditions Water Surface Profiles (upstream) 168
Figure 138: Proposed Conditions Water Surface Profiles (downstream) 169
Figure 139: Typical Section in Proposed Reach A, Upstream Channel (Sta. 23+14) 170
Figure 140: Typical Section through Proposed Structure 1 (Sta. 19+38) 171
Figure 141: Typical Section Between I-5 Southbound and I-5 Northbound (Sta. 18+60) 172
Figure 142: Typical Section in Structure 2 (Sta. 18+08) 173
Figure 143: Typical Proposed Section Within Proposed Reach B, east of I-5 (Sta. 16+45) 174
Figure 144: Typical Section Within Structure 3, under the I-5 Northbound Off-Ramp (Sta. 14+37) 175
Figure 145: Proposed Conditions 2080 Predicted 100-Year Velocity Map (upstream) 178
Figure 146: Proposed Conditions 2080 Predicted 100-Year Velocity Map (downstream) 179
Figure 147: Comparison of Proposed Upstream Bed Material to Pebble Counts and Fuller-Thompson Gradation 188
Figure 148: Comparison of Proposed Reach B to Downstream Design Reach Pebble Count and Fuller-Thompson Gradation 190
Figure 149: Preliminary Concept for Step-Pools Within Structure 1 and Structure 2 193
Figure 150: Conceptual Layout of Habitat Complexity Proposed Reach A (upstream) 198
Figure 151: Conceptual Layout of Habitat Complexity Proposed Reach B (downstream) 199
Figure 152: Typical Large Woody Material Placement Exhibit 200

Tables

Table 1: South Tributary Existing WSDOT Barrier Summary......2
Table 2: Existing Land Uses Within the South Tributary Watershed......5
Table 3: South Tributary Barrier Summary......13
Table 4: Native Fish Species Potentially Present Within Friday Creek Downstream of the Project Area......17
Table 5: South Tributary Summary of Habitat, Spawning, and Rearing Gains......39
Table 6: Summary of Step-Pool Measurements Within Upstream Reference Reach......42
Table 7: Reference and Design Reach Channel Morphology Categories (by slope)......45
Table 8: South Tributary Bankfull Width Measurements Collected in Upstream Reference Reach......50
Table 9: South Tributary Bankfull Width Measurements Collected in Project Reach and Downstream Reach......56
Table 10: South Tributary Bankfull Width Measurements Collected in Downstream Design Reach......58
Table 11: South Tributary Pebble Count Gradation Within the Reference Reach......66
Table 12: South Tributary Downstream Reach Pebble Count Data......69
Table 13: South Tributary Downstream Design Reach Pebble Count Data......71
Table 14: Peak Flows for the South Tributary at I-5/Lake Samish Road Interchange......83
Table 15: MGSFLOOD Peak Flows for South Tributary at I-5/Lake Samish Road Interchange......84
Table 16: Summary of Mesh Elements Within Existing, Natural, and Proposed Conditions Models......86
Table 17: Manning's n Hydraulic Roughness Coefficient Values Used in the Existing Conditions SRH-2D Model......98
Table 18: Manning's n Hydraulic Roughness Coefficient Values Used in the Natural Conditions SRH-2D Model......99
Table 19: Manning's n Hydraulic Roughness Coefficient Values Used in the Proposed Conditions SRH-2D Model......99
Table 20: Discharge Values Used in the SRH-2D Model......104
Table 21: Average Hydraulic Results for Existing Conditions......121
Table 22: Existing Conditions Velocities Including Floodplains at Select Cross Sections......133
Table 23: Floodplain Utilization Ratio Calculations near the I-5/Lake Samish Road Interchange......133
Table 24: Natural Conditions Velocities Including Floodplains at Select Cross Sections......144

Table 25: Approximate Sinuosity, Meander Amplitude, and Meander Length of Proposed Reach A and Proposed Reach B Compared to the Upstream Reference Reach....147
Table 26: Upstream Reference Reach and Downstream Design Reach Typical Dimensions 148
Table 27: Proposed Typical Cross-Section Dimensions for Proposed Reach A and Proposed Reach B by Longitudinal Slope....148
Table 28: Average Main Channel Hydraulic Results for Proposed Conditions Upstream (Sta. 20+12) and Downstream (Sta. 18+89) of Structure 1 162
Table 29: Average Main Channel Hydraulic Results for Proposed Conditions Within Structure 1 (Sta. 19+38) 162
Table 30: Average Main Channel Hydraulic Results for Proposed Conditions Upstream (Sta. 18+37) and Downstream (Sta. 17+72) of Structure 2 162
Table 31: Average Main Channel Hydraulic Results for Proposed Conditions Within Structure 2 (Sta. 18+08) 162
Table 32: Average Main Channel Hydraulic Results for Proposed Conditions Upstream (Sta. 15+44) and Downstream (Sta. 13+12) of Structure 3 163
Table 33: Average Main Channel Hydraulic Results for Proposed Conditions Within Structure 3 (Sta. 14+37) 163
Table 34: Proposed Velocities Including Floodplains at Select Cross Sections for the 100-Year Flow....176
Table 35: Proposed Velocities Including Floodplains at Select Cross Sections for the 2080 Project 100-Year Flow....177
Table 36: Proposed Length, Hydraulic Opening, and Length to Width Ratio by Structure 181
Table 37: Velocity Comparison for Structure 1, 24-Foot Span Structure 181
Table 38: Velocity Comparison for Structure 2, 24-Foot Span Structure 181
Table 39: Velocity Comparison for Structure 3, 28-Foot Span Structure 181
Table 40: Comparison of Observed and Proposed Streambed Material for Proposed Reach A 187
Table 41: Comparison of Observed and Proposed Streambed Material for Proposed Reach B 189
Table 42: Calculated Maximum Mobile Particle Size for Streambed Gravel Gradation with D_{50} of 0.9 Inch 191
Table 43: Typical Dimensions from Preliminary Step-Pool Concept Within Structure 1 and Structure 2....192
Table 44: Meander Bars Gradation for Structures 1 and 2, with Slopes Greater than 4 Percent....195
Table 45: Calculated Maximum Mobile Particle Size for Meander Bars Within Structure 3, with D_{50} of 1.8 Inches 195

Table 46: Comparison of Large Wood Number and Volume in Design to Target Loading from Fox and Bolton (2007) 197
Table 47: Report Summary Table 210

1 Introduction

To comply with United States, et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 to 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the Interstate 5 (I-5) crossing of an unnamed tributary to Friday Creek at milepost (MP) 240.92 and MP 240.95. There are three unnamed tributaries to Friday Creek proposed for fish-passage projects by WSDOT; therefore, the tributary is referred to as the South Tributary to Friday Creek (South Tributary) throughout this report. Six existing structures have been identified as fish barriers by Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (Figure 1). The Site Identification Numbers (Site ID) of the existing six culverts, listed upstream to downstream, are: 995236, 995235, 995234, 995233, 995232, and 995245 (Figure 2). The project includes an estimated 4,209 linear feet (1,283 meters) of habitat gain as identified in WDFW's Level A Culvert Assessment Report (WDFW 2011a for Culvert 995245). In addition, the new proposed stream alignment included as part of the project will provide an additional 179 linear feet of stream channel habitat.

Per the federal injunction, and in order of preference, fish passage should be achieved by (a) avoiding the necessity for the roadway to cross the stream, (b) use of a full span bridge, or (c) use of the stream simulation methodology. WSDOT evaluated all six of the crossings of the South Tributary and determined the upgraded crossings could be addressed in one Preliminary Hydraulic Design (PHD) due to the proximity of the road crossings along the South Tributary. WSDOT determined that stream simulation is suitable for the South Tributary crossings due to the existing bankfull width (BFW) of less than 15 feet and confinement at the I-5 crossing. All crossing designs presented in the following PHD for the South Tributary followed the stream simulation methodology including the *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013).

The crossings are located in Skagit County, approximately 0.7 mile west of Alger, Washington, in WRIA 3 (Lower Skagit). I-5 runs approximately north-south at this location and intersects the South Tributary approximately 1,820 feet from its coFnfluence with Friday Creek. The South Tributary generally flows west to east beginning in the headwaters approximately 0.5 mile upstream of the I-5/Lake Samish Road interchange (see Figure 1).

The proposed project will replace six existing culverts (see Table 1) with three crossing structures designed with minimum hydraulic openings that vary from 24 feet wide to 28 feet wide. The proposed structures are designed to meet the requirements of the federal injunction using the stream simulation design criteria as described in the 2013 WCDG (Barnard et al. 2013). The proposed design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2022a).

Table 1: South Tributary Existing WSDOT Barrier Summary

Structure ID	Length (feet)	Diameter (feet)	Structure Type
995236	52.8	2.0	Culvert
995235	167.0	2.0	Culvert
995234	64.9	2.0	Culvert
995233	44.9	2.0	Culvert
995232	73.1	2.0	Culvert
995245	228.6	2.5	Culvert

Note: Structures are listed upstream to downstream along the South Tributary.

Structure types are not being recommended in this report and will be determined by others during future design phases.

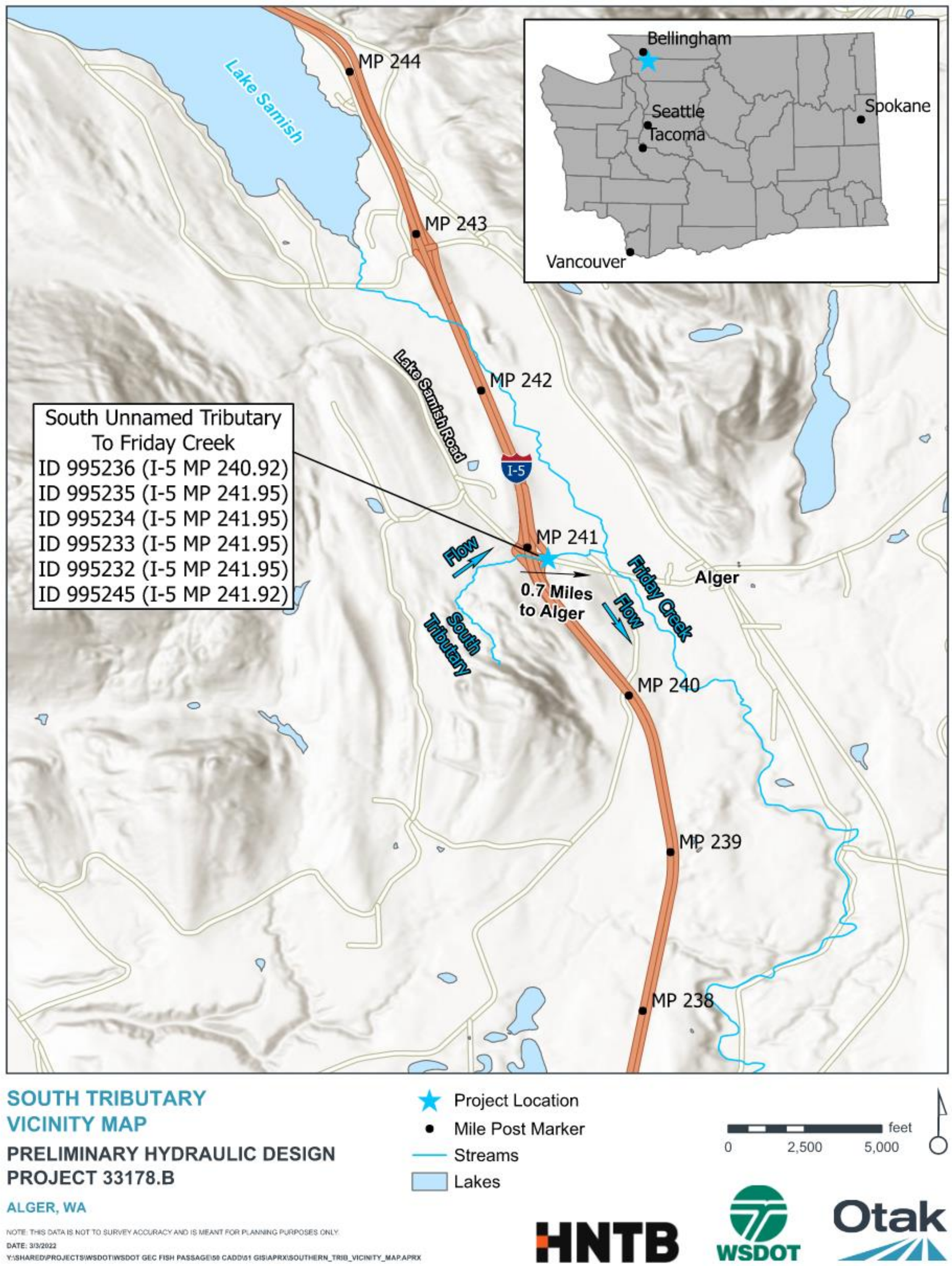


Figure 1: Vicinity Map

Figure 2: South Tributary Culverts in the Vicinity of I-5/Lake Samish Road Interchange

2 Watershed and Site Assessment

2.1 Watershed and Land Cover

The culvert crossings are located approximately 0.7 mile west of Alger in Skagit County, on the South Tributary to Friday Creek. The South Tributary generally flows west to east from its headwaters to its confluence with Friday Creek (Figure 3). Friday Creek originates at Lake Samish and flows south through a wide valley where it joins the Samish River north of Burlington in unincorporated Skagit County. The South Tributary flows north from its headwaters in the steeper, higher foothills area west of I-5, east through the I-5/Lake Samish Road interchange culverts located along the alluvial fan and transitional zone at the valley margin, and east towards its confluence with Friday Creek within a wide, alluvial valley. The construction of the I-5/Lake Samish Road interchange in the early 1960s altered the course of the South Tributary and conveyed the stream through the series of culverts at the interchange. The South Tributary has a dendritic drainage network pattern with an upstream contributing area of 0.17 square mile (approximately 111 acres) above Culvert 995245) and has a maximum stream elevation of approximately 600 feet and a minimum elevation of 245 feet at its confluence with Friday Creek (Figure 4).

Land use along the South Tributary is predominantly private/commercial forested land upstream of the I-5/Lake Samish Road interchange, utilities and transportation through the I-5 interchange, and agricultural downstream of I-5 within the valley bottom (Figure 5) (Table 2). A portion of the watershed was clear-cut between the years of 1976 and 1981 (Figure 6). There is one culvert (931904; WDFW 2011b) associated with a logging access road within the watershed upstream of the I-5/Lake Samish Road interchange (Figure 3). The South Tributary then passes through the six culverts associated with the I-5/Lake Samish Road interchange (995236, 995235, 995234, 995233, 995232, and 995245) (Figure 2). Downstream of the I-5/Lake Samish Road interchange, the stream crosses under Barleen Road via a private culvert (931905). The private Culvert 931905 is zero percent passable with the reason listed as slope by WDFW (WDFW 2011c).

Table 2: Existing Land Uses Within the South Tributary Watershed

Land Use Class	Area (acres)	Area (%)
Private/Commercial Forest	94.7	85.7
Utility – Transportation (Includes I-5)	11.3	10.2
Single Family Residential	4.5	4.1

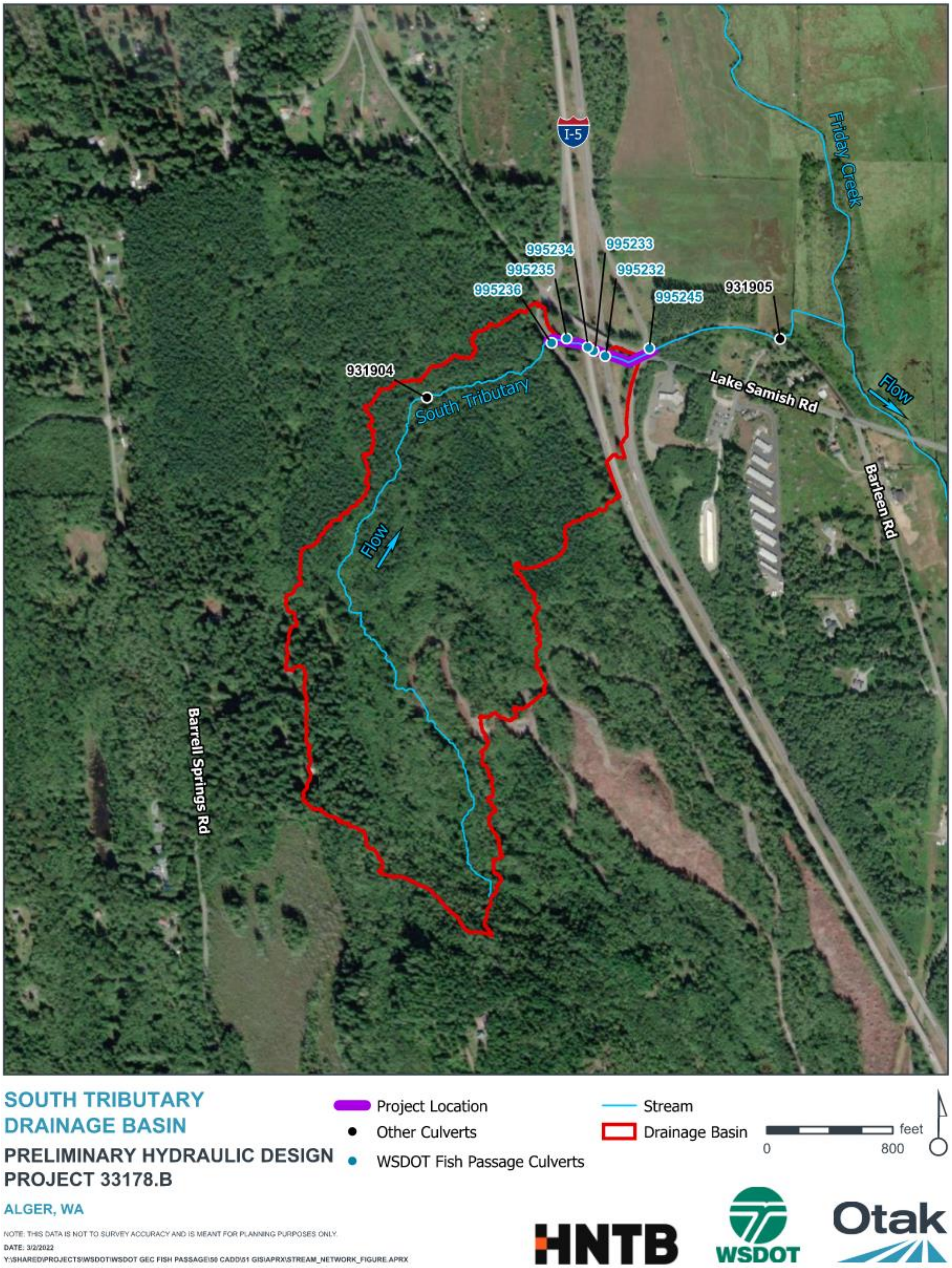


Figure 3: South Tributary Drainage Basin (based on 2016 LiDAR)

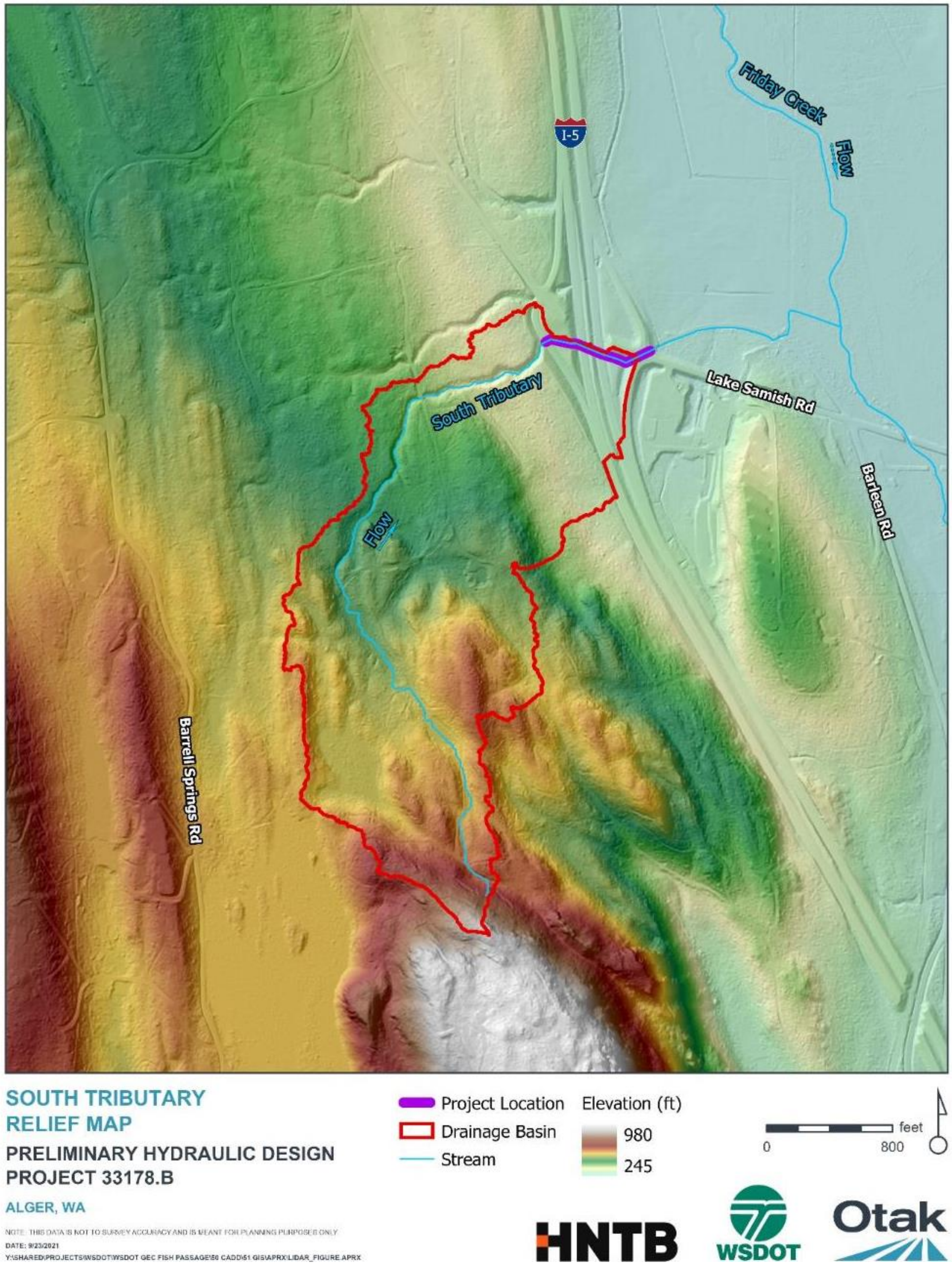


Figure 4: South Tributary Relief Map (based on 2016 LiDAR)

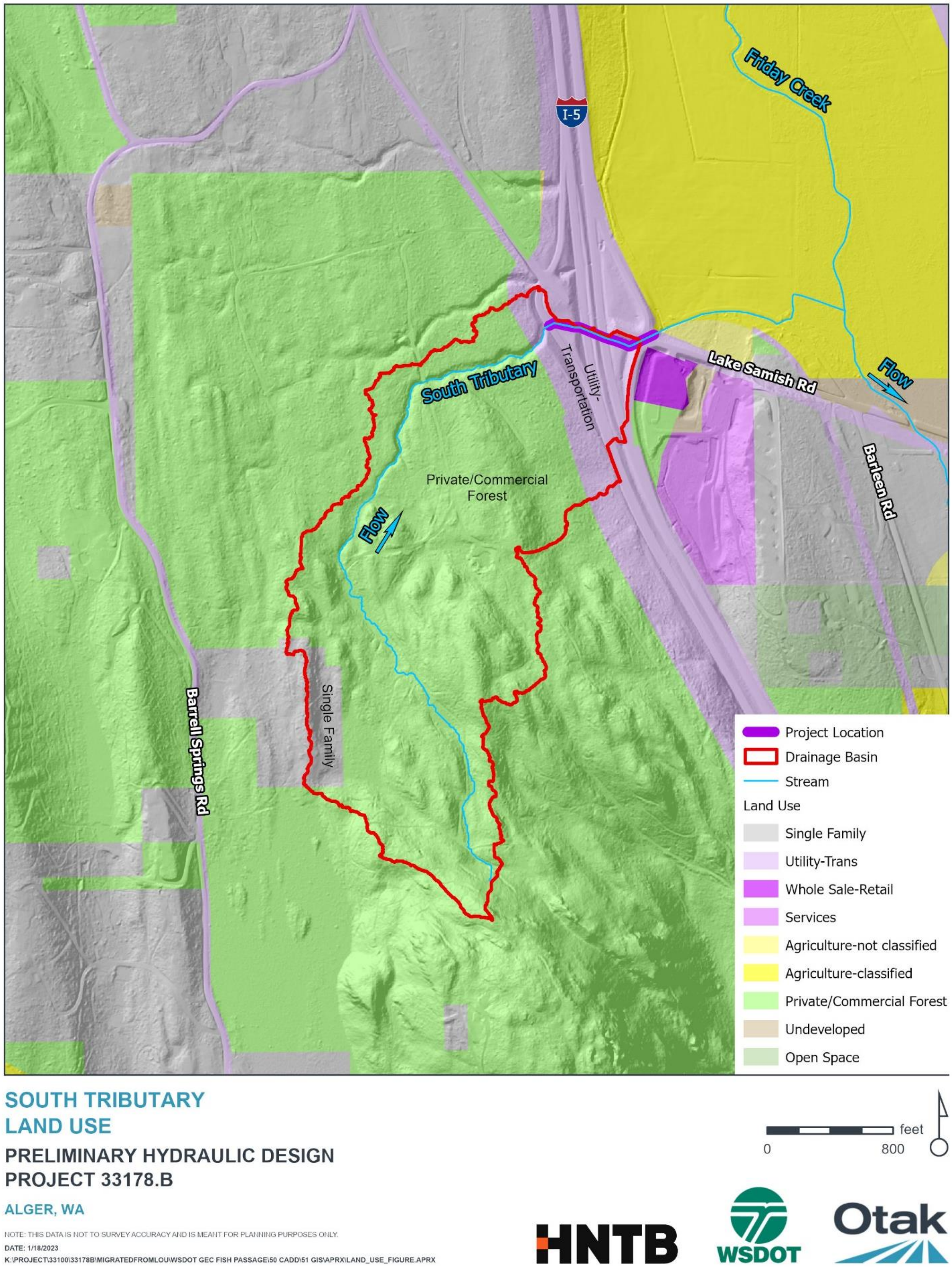


Figure 5: Land Use in the Vicinity of the South Tributary Project Area

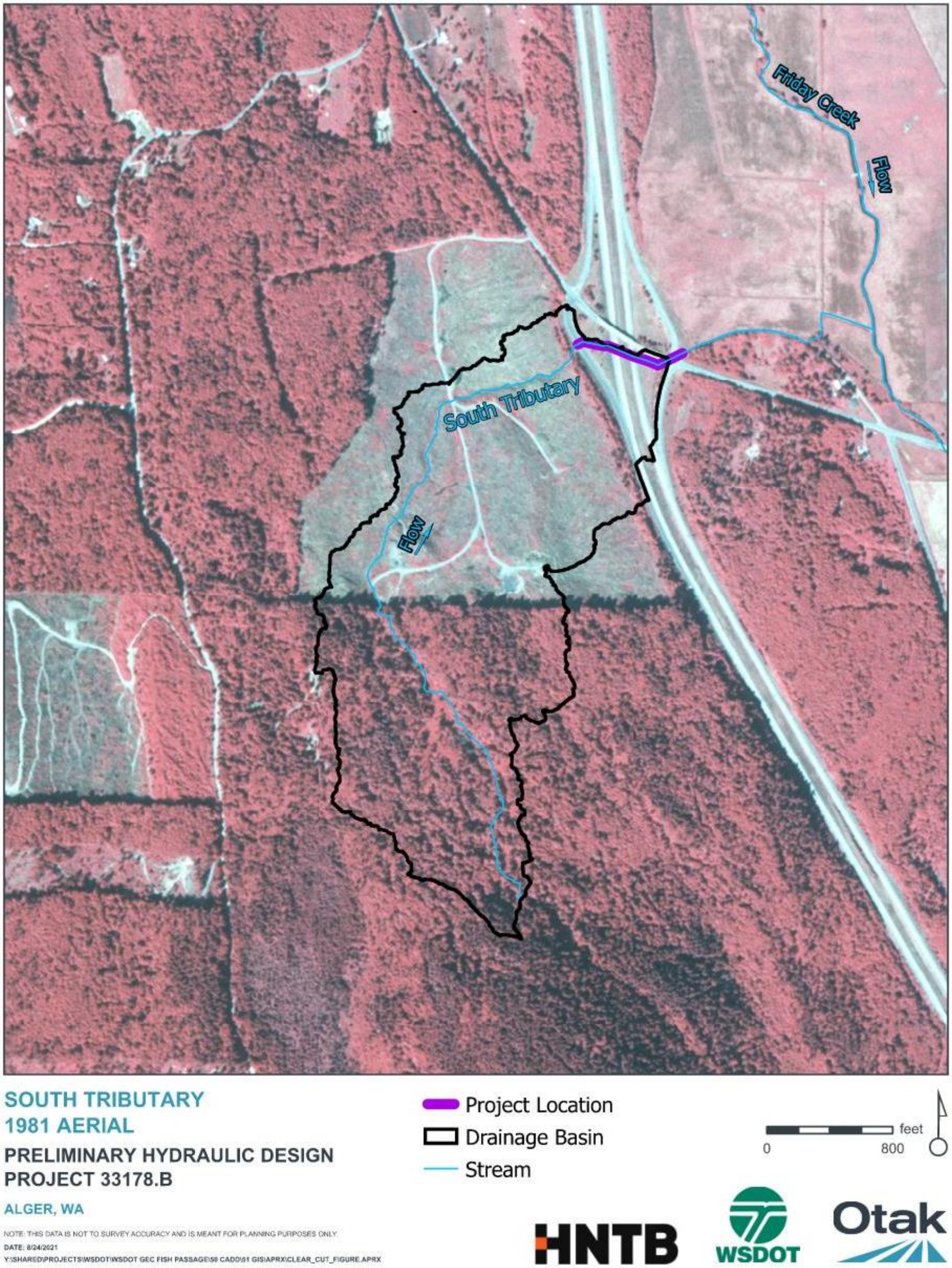


Figure 6: Historical Aerial Image of South Tributary Watershed from 1981

2.2 Geology and Soils

The existing topography reflects past movement along local faults as well as regional tectonic uplift and erosion, resulting in the formation of steep, valley-margin hillslopes and tributaries adjacent to the broader, lower-gradient valley bottom containing Friday Creek. More recently, this area was subject to numerous continental glaciation advances that deposited the sediments that comprise the surficial geologic units found at the project site (Figure 7) (Lapen 2000).

In the project vicinity, the lower relief areas and valley bottoms consist of sediments deposited during the last continental glaciation advance (Vashon Stade of the Fraser Glaciation) that occurred about 18,000 years ago (Bellingham area) and the areas of high relief and hill tops (such as Chuckanut Mountain and Lookout Mountain) consist of the older metamorphic rocks (Darrington phyllite, Jurassic Period) and sedimentary rocks of the Chuckanut Formation (Eocene Epoch of the Tertiary Period). The steep, high topography west of I-5 and the knoll southeast of the I-5/Lake Samish Road interchange consist of high- to medium-density Quaternary glacial till deposits (Vashon Stade) with lenses of coarse sands and gravels. Underlying these Quaternary glacial tills is the low-grade metamorphic Darrington phyllite that outcrops sporadically in the upper portions of the watershed. East of the I-5/Lake Samish Road interchange, within the broad valley bottom occupied by Friday Creek, are younger (Everson Interstate), low-density, fine-grained glacial marine drift deposits, consisting of silts and clays with periodic lenses of sands and gravel outwash.

The project site is located at the transition zone where the South Tributary changes from a higher-gradient, confined stream to a lower-gradient stream as it enters the valley and floodplain of Friday Creek. This transition zone is where deposition is expected to naturally occur, which has resulted in the development of an alluvial fan. The soil data generally follow geologic patterns with Vanzandt very gravelly loam on the steeper hillslopes to the west of I-5, Hoogdal silt loam in the vicinity of the I-5/Lake Samish Road interchange, and Skipopa silt loam to the east, consistent with a downstream and downslope fining of material from the steeper topography in the west to the valley bottom in the east (Figure 8) (NRCS 2020).

Throughout the basin, the soils and surficial glacial deposits provide sediment sources for the stream to transport from the steeper upper reaches and deposit in the lower slope areas at the valley bottom (below I-5). Landslides are not mapped in the basin per Lapen (2000) (Figure 8). Due to the forested conditions in the upper basin areas, sediment inputs from surface runoff and erosion are minimal.

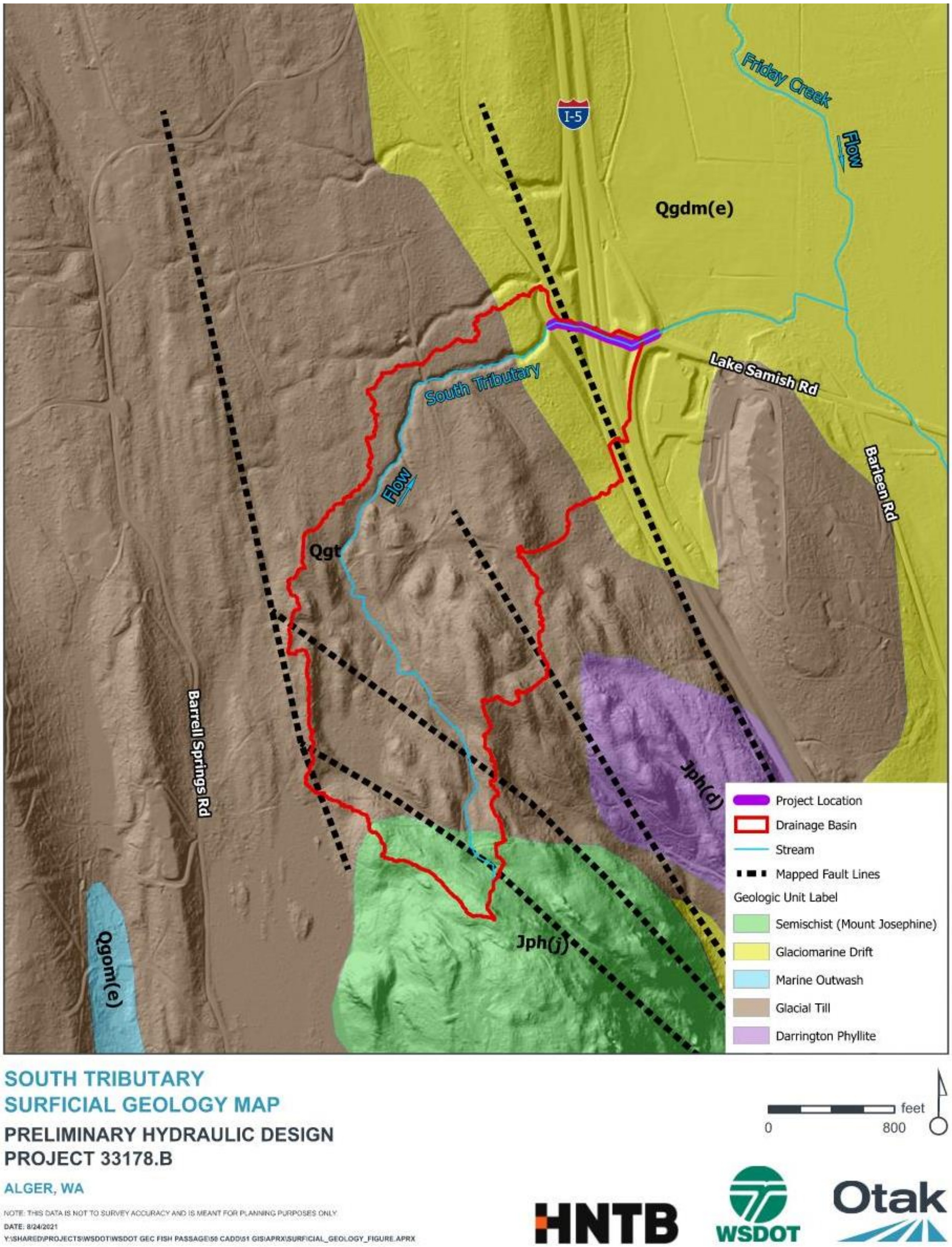


Figure 7: Surficial Geology Map in the Vicinity of the South Tributary Project Area (based on Lapen 2000)

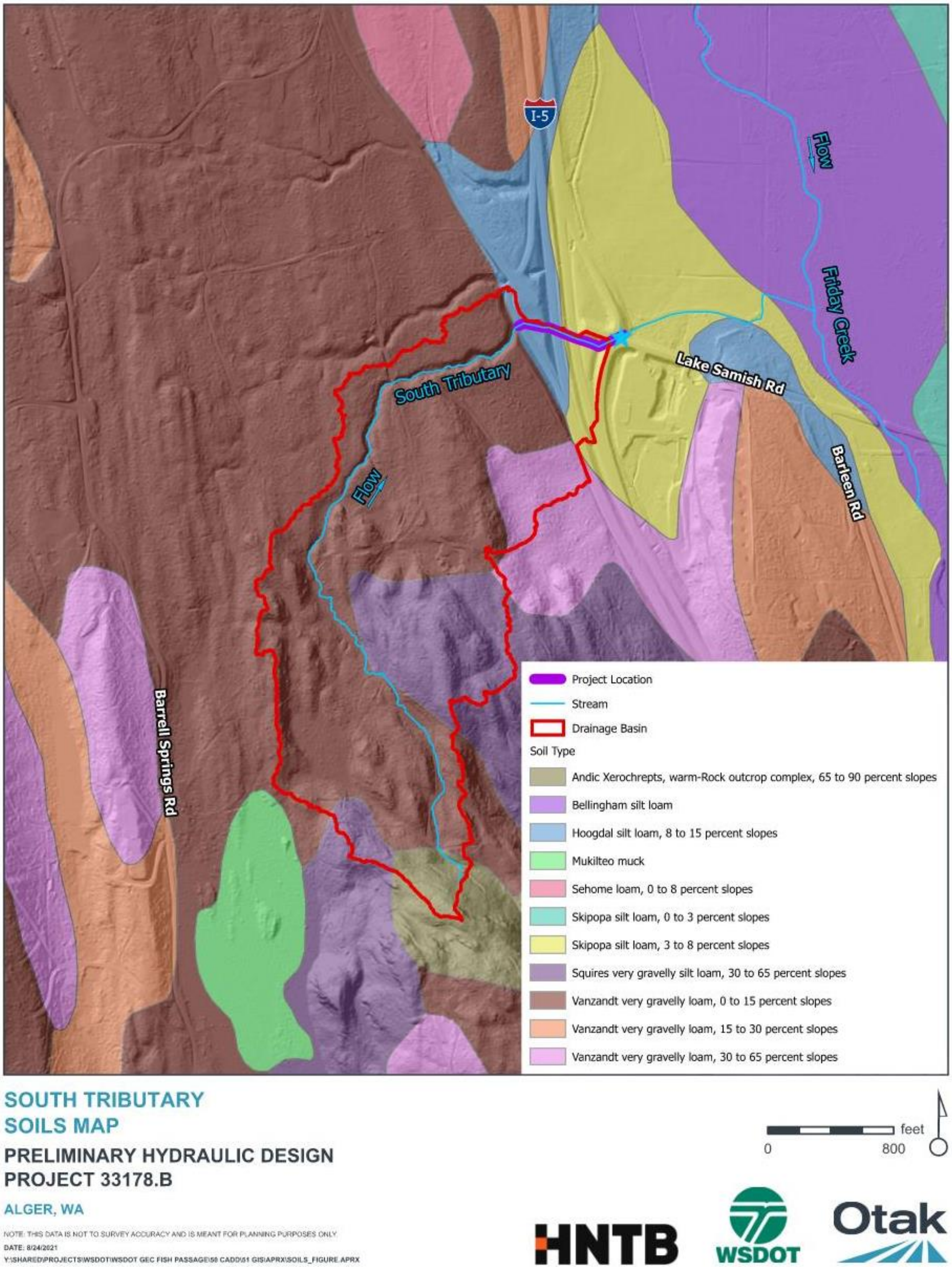


Figure 8: Soils in the Vicinity of the South Tributary Project Area

2.3 Floodplains

The I-5/Lake Samish Road interchange is not located within a Federal Emergency Management Agency (FEMA) mapped floodplain Special Flood Hazard Area (SFHA) on the most recent Flood Insurance Rate Map (FIRM) panel (No. 530151005C), effective date January 3, 1985 (Appendix A; FEMA 1985). The project site and surrounding area are designated Zone C, an area of minimal flooding, on the FIRM. The closest flood zone (Zone A—1 percent annual chance of flooding) is associated with Friday Creek located approximately 1,700 feet east of Culvert 995236 along the South Tributary (Appendix A). Considering the project is located outside of an SFHA, a local floodplain development permit will not be required. Flooding of I-5 at the South Tributary crossing site has not been documented by WSDOT (Case, personal communication, April 21, 2021).

2.4 Site Description

At the project site, the South Tributary flows as a single-thread channel through a series of six culverts, approximately 630 feet in length in total, under the I-5/Lake Samish Road interchange (Figure 2; Table 3). The culverts range in length from 44.9 feet (995233) to 228.6 feet at the most downstream culvert (995245). There is minimal daylighting of the stream between each culvert. At the I-5/Lake Samish Road Interchange, the stream flows down a steep grade (with slopes ranging from 1.6 to 13.0 percent) and then flows into the Friday Creek valley and floodplain. See Section 2.8.4 (Vertical Channel Stability) for a discussion of existing channel slopes along the existing stream alignment.

Table 3: South Tributary Barrier Summary

Structure ID	Length (feet)	Diameter (feet)	Structure Type	Material	Passable (%)	Barrier Reason	Slope (%)
995236	52.8	2.0	Culvert	Precast Concrete	33	Slope	3.16
995235	167.0	2.0	Culvert	Corrugated Steel	0	Slope	11.15
995234	64.9	2.0	Culvert	Precast Concrete	33	Velocity	0.86
995233	44.9	2.0	Culvert	Corrugated Steel	0	Slope	6.11
995232	73.1	2.0	Culvert	Precast Concrete	33	Slope	1.66
995245	228.6	2.5	Culvert	Concrete/ Corrugated Steel	0	WSE Drop (1.4 feet)	2.73

The stream alignment through the upper five culverts is generally northwest to southeast (listed upstream to downstream: Culverts 995236, 995235, 995234, 995233, 995232). At the most downstream culvert (995245), the stream alignment shifts to the northeast under Lake Samish Road and the I-5 northbound off-ramp. The stream slope drops abruptly as the stream enters the Friday Creek valley floor and floodplain. At this transition point, sediment deposition is observed at the downstream culverts (995233 and 995232). Land cover within this downstream reach below the I-5/Lake Samish Road interchange consists of mostly agricultural fields with a few residential structures.

The construction and alignment of I-5 along the valley wall margin has altered the South Tributary's natural channel and geomorphic conditions and processes. The I-5 corridor is located at the transition zone where the South Tributary changes from a higher-gradient, confined stream to a lower-gradient stream as it enters the valley and floodplain of Friday Creek. This transition zone is where deposition is expected to naturally occur, creating an alluvial fan. The I-5 corridor and the conveyance of the stream through a series of culverts has altered the natural alluvial fan processes. Under natural conditions, the stream would be adjusting its slope and alignment within the fan footprint as it responds to changes in flow and the influx of sediment.

The existing six barrier culverts are discussed below (upstream to downstream) and are presented in Table 3. Removal of the six barrier culverts would result in estimated habitat gains of 4,208.2 linear feet of stream habitat, 4,540.7 square feet (ft^2) of spawning habitat, and 9,974.5 ft^2 of rearing habitat along the South Tributary upstream of Culvert 995245 (WDFW 2011a).

Culvert ***995236***

Culvert 995236 is a precast round concrete culvert 52.8 feet in length and 2 feet in diameter (WDFW 2011d). This culvert conveys the South Tributary under the southbound on-ramp lane to I-5. Based on the WDFW Level A Assessment, this culvert is 33 percent passable with the barrier reason listed as slope (3.16 percent; WDFW 2011d). During the site reconnaissance, the culvert was passing all flows and did not appear to have any blockages. The culvert's steep slope over its 52.8-foot length is a barrier to fish passage (WDFW 2011d). Over the length of the structure, there is likely no opportunity for the fish to rest or hold (lack of pools) during passage upstream due to the plane-bed conditions and high water velocities inside the culvert, prohibiting upstream fish passage. Immediately downstream of this culvert, the stream flows into the next downstream culvert (995235).

Per the WSDOT Culvert Inspection Report, no record of repairs or cleanings exists for this culvert (WSDOT 2021a). This culvert is not identified as a Chronic Environmental Deficiency (CED) site by WSDOT.

Culvert 995235

Culvert 995235 is a corrugated-steel culvert 167 feet in length and 2 feet in diameter (WDFW 2011e). This steep culvert conveys stream flows under the open area between the I-5 on-ramp southbound lane and the I-5 southbound lanes. Based on the WDFW Level A Assessment, this culvert is zero percent passable because of excessive slope, 11.15 percent (WDFW 2011e). The culvert's steep slope prevents upstream fish passage (WDFW 2011e). The long structure provides no opportunity for fish to rest or hold (lack of pools) during passage upstream due to the plane-bed conditions and high water velocities inside the culvert, prohibiting upstream fish passage. Immediately downstream of this culvert, the stream flows into the next downstream culvert (995234).

Per the WSDOT Culvert Inspection Report, no record of repairs or cleanings exists for this culvert (WSDOT 2021b). This culvert is not identified as a CED site by WSDOT.

Culvert 995234

Culvert 995234 is a precast concrete culvert 64.9 feet in length and 2 feet in diameter (WDFW 2011f). The culvert conveys the South Tributary under the southbound I-5 lanes. Based on the WDFW Level A Assessment, this culvert is 33 percent passable because of excessive velocity and has a slope of 0.86 percent (WDFW 2011f). The culvert’s high-water velocities prevent fish passage through the structure (WDFW 2011f). With the plane-bed conditions inside the culvert, there are no pools or other features for the fish to seek velocity refugia inside the culvert, prohibiting upstream fish passage. Immediately downstream of this culvert, the stream flows into the next downstream culvert (995233).

Per the WSDOT Culvert Inspection Report, no record of repairs or cleanings exists for this culvert (WSDOT 2021c). This culvert is not identified as a CED site by WSDOT.

Culvert 995233

Culvert 995233 is a corrugated-steel culvert 44.9 feet in length and 2 feet in diameter (WDFW 2011g). The culvert conveys the South Tributary through the grassy median between the northbound and southbound lanes of I-5. Based on the WDFW Level A Assessment, this culvert is zero percent passable because of excessive slope (6.11 percent; WDFW 2011g). Immediately downstream of this culvert, the stream flows into the next downstream culvert (995232). Based on field observations by Otak, Inc. (Otak), sediment accumulates at the grade break between the outlet of Culvert 995233 and the inlet of Culvert 955232. The abrupt grade break between the culverts disrupts the sediment transport continuity through the project reach, resulting in sediment deposition starting at the outlet of Culvert 995233 and continuing downstream to Culvert 995232. The sediment fills the channel and blocks the culvert opening preventing fish passage.

Per the WSDOT Culvert Inspection Report, no record of repairs or cleanings exists for this culvert (WSDOT 2021d). This culvert is not identified as a CED site by WSDOT.

Culvert 995232

Culvert 995232 is a precast concrete culvert 73.1 feet in length and 2 feet in diameter (WDFW 2011h). The culvert conveys the South Tributary under the northbound I-5 lanes. Based on the WDFW Level A Assessment, this culvert is 33 percent passable with the barrier reason listed as slope (1.66 percent) (WDFW 2011h). Downstream of this culvert, the stream flows for approximately 130 feet in an open channel before flowing into the next downstream culvert (995245). Based on field observations by Otak, there is sediment aggradation at the culvert’s inlet and outlet. This sediment blockage is a barrier that prevents fish passage through the structure and prevents access to the upstream culverts at the project site. In addition, sediment and woody material transport is disrupted.

Per the WSDOT Culvert Inspection Report, no record of repairs or cleanings exists for this culvert (WSDOT 2021e). However, based on information from WSDOT staff, the South Tributary had 15 cubic yards of material removed from the outlet side in 2018 (Case, personal communication, April 21, 2021). This culvert is not identified as a CED site by WSDOT.

Culvert 995245

Culvert 995245 is a precast concrete and steel culvert 228.6 feet in length and 2.5 feet in diameter. The culvert conveys the South Tributary under the northbound off-ramp lane at the I-5/Lake Samish Road interchange. Based on the WDFW Level A Assessment, this culvert is zero percent passable because of excessive water surface drop (WDFW 2011a). The culvert inlet is partially submerged with sediment. The culvert outlet is perched with a water surface drop of 1.4 feet (as reported by WDFW) and is a physical barrier for upstream fish movement.

Per the WSDOT Culvert Inspection Report, no record of repairs or cleanings exists for this culvert (WSDOT 2021f). Nor is this culvert identified as a CED site by WSDOT.

Culvert near Milepost (MP 240.86)

An additional culvert is located near I-5 approximate MP 240.86, about 300 feet south of Culvert 995236. The culvert near MP 240.86 conveys flows from the ditch and hillside on the west side of I-5, to the median east of the northbound I-5 lanes, to the inlet of Culvert 995245.

2.5 Fish Presence in the Project Area

According to the Statewide Washington Integrated Fish Distribution (SWIFD) website managed by WDFW and Northwest Indian Fisheries Commission (NWIFC), Friday Creek (a tributary to the Samish River), in the vicinity of the project site is mapped for presumed presence of fall Chinook salmon (*Oncorhynchus tshawytscha*), documented presence for odd-year pink salmon (*O. gorbuscha*), rainbow trout (*O. mykiss*), and kokanee (*O. nerka*) (WDFW 2020a). The SWIFD website map shows documented spawning in Friday Creek (project vicinity) for coho salmon (*O. kisutch*), fall chum salmon (*O. keta*), and winter steelhead (*O. mykiss*) (WDFW 2020a). In addition, per the Washington State Fish Passage and Diversion Screening Inventory (FPDSI) database and SWIFD, resident coastal cutthroat (*O. clarkii*) also has a documented presence in Friday Creek per WDFW (WDFW 2020a, 2020b). A reach of the South Tributary downstream of Barleen Road is mapped for documented presence for coho salmon () (WDFW 2020a, 2020b), and the entire reach of the South Tributary downstream of Barleen Road to Friday Creek is mapped for documented presence for cutthroat trout () (WDFW 2020a, 2020b).

The Puget Sound Evolutionarily Significant Unit of Chinook salmon is listed as Threatened under the Endangered Species Act (ESA) and as a State Candidate species. The Puget Sound Distinct Population Segment of steelhead is listed as Threatened under the ESA. Coho salmon are listed as a Federal Species of Concern for the Puget Sound/Strait of Georgia Evolutionarily Significant Unit by the National Marine Fisheries Service.

Table 4: Native Fish Species Potentially Present Within Friday Creek Downstream of the Project Area

Species	Presence (Presumed, Modeled, or Documented)	Data Sources SWIFD, FPDSI.	ESA Listing
Fall Chinook salmon (*Oncorhynchus tshawytscha*)	Presumed presence	SWIFD, FPDSI.	Threatened
Winter steelhead (*Oncorhynchus mykiss*)	Documented spawning	SWIFD, FPDSI.	Threatened
Fall chum salmon (*Oncorhynchus keta*)	Documented spawning	SWIFD, FPDSI.	N/A
Coho salmon[a] (*Oncorhynchus kisutsh*)	Documented spawning	SWIFD, FPDSI.	State Candidate species of concern
Cutthroat trout[b] (*Onncorhyncus clarkii*)	Documented presence	SWIFD, FPDSI.	N/A
Rainbow trout (*Oncorhynchus mykiss*)	Documented presence	SWIFD, FPDSI.	N/A
Kokanee (*Oncorhynchus nerka*)	Documented presence	SWIFD, FPDSI.	N/A
Pink salmon, odd year (*Oncorhynchus gorbuscha*)	Presumed presence	SWIFD, FPDSI.	N/A

a. Also identified in the South Tributary for a portion of the channel reach between Barleen Road and Friday Creek for documented presence (WDFW 2020a, 2020b).

b. Also identified in the South Tributary downstream of the project site for the channel reach between Barleen Road and Friday Creek for documented presence (per SWIFD and FPDSI websites [WDFW 2020a, 2020b]).

Several map sources have been used to identify fish species within the project area. Fish data included in this report were collected from SWIFD (WDFW 2020a) and the FPDSI database (WDFW 2020b). WDFW's Level A Culvert Assessment Report was used to identify fish species that would likely be present in each stream if the culvert barriers were removed. It should be noted that naturally steep gradients upstream of Culvert 995236 (ranging between 7 percent and 8 percent) could preclude utilization by some salmonid species at some life stages during high flows (WDFW 2019). However, survey data are not available for current fish populations at or above the project culverts.

The WDFW Fish Passage Program uses the Priority Index (PI) to consolidate several variables that affect the feasibility of a fish-passage project, including expected passage improvement, habitat gain, fish stock status, etc. Habitat gain values are derived from the physical Level A habitat survey and subsequent data analysis (Chapters 10 and 11) in the WDFW *Fish Passage Inventory, Assessment, and Prioritization Manual* (WDFW 2019). It should be noted that spawning and rearing habitat gain values used to calculate the WDFW PI value for each culvert do not represent actual habitat available for a given species.

The project culverts are a combination of three partial and three total barriers to fish passage (see the site descriptions in Section 2.4). Due to these barriers, anadromous fish have not been documented on or above the project site. The WDFW culvert analysis data estimate a PI to determine feasibility of future culvert replacement.

The WDFW FPDSI database indicates that coho salmon fry were observed below the private Culvert 931905 in May 2011 during the culvert survey (WDFW 2011c). The South Tributary is ditched to the confluence with Friday Creek. This culvert is east of the project site near the junction of Vaughn Road and Barleen Road (Figure 3).

At the project site, beginning at Culvert 995245, the lower section, the FPDSI also documented coho salmon fry in the channelized ditch section below this culvert in May 2011 (WDFW 2011a). PI species below this culvert include winter steelhead, resident coastal cutthroat trout, and resident rainbow trout.

The SWIFD shows that the streams above and through the I-5/Lake Samish Road interchange are mapped as type F streams (fish-bearing streams), which includes stream data from the Washington Department of Natural Resources (DNR). Type F streams may include both resident and anadromous fish as long as there are no natural barriers, such as gradients, that limit passage or migration. SWIFD includes documented presence for coastal cutthroat trout and coho salmon within the lower reach of the South Tributary below Barleen Road (WDFW 2020a). Fish use in the project area is listed in .

The highway culverts have likely fragmented and isolated the resident fish populations. Restoring connectivity of the upper South Tributary to lower Friday Creek by replacing the barrier highway culverts will allow populations of resident and anadromous fish easier access to the reach upstream of I-5. It is uncertain whether these species would access the upstream reach due to downstream private barrier (Culvert 931905) located downstream of the project site in the South Tributary.

The review of data sources did not indicate documentation of resident or anadromous fish species above I-5. Replacing the culverts will improve stream flow (rearing) and sediment conditions (spawning) for Chinook, coho, and chum salmon; cutthroat trout; and resident fish.

2.6 Wildlife Connectivity

The one-mile road segment that the South Tributary falls in is ranked medium priority for Wildlife-related Safety (Kalisz, personal communication, November 1, 2021). Adjacent segments to the north are ranked medium priority, and segments to the south ranked low priority for Wildlife-related Safety (Kalisz, personal communication, November 1, 2021). Ecological Stewardship for the crossing location or adjacent road segments is ranked low (Kalisz, personal communication, November 1, 2021). WSDOT has determined that, in order tobe eligible for a habitat connectivity analysis, fish barrier correction projects must fall in or adjacent to a ranked high priority road segment, or a project team member can request the analysis. Therefore, WSDOT is not planning to prepare a wildlife connectivity memo for the I-5/Lake Samish Road interchange. The Habitat Connectivity Investment Priorities are the agreed upon method for determining which fish-passage projects receive a full connectivity evaluation and are outlined in WSDOT's Executive Order Number E 1031.02 (WSDOT 2019).

2.7 Site Assessment

The site assessment by Otak included collection of topographic survey, selection of the reference reach, and a stream survey to complete the Hydraulic Field Report Form (attached as Appendix B). The information in the Hydraulic Field Report is based on a site assessment visit conducted on January 27, 2021. This report summarizes the existing conditions found in the South Tributary upstream and downstream of the I-5/Lake Samish Road interchange and includes photo documentation. The site reconnaissance also included an assessment of the existing crossings (Figure 2). Site conditions at the crossings are discussed in detail in Section 2.7.2. The site assessment included documenting stream conditions upstream of I-5 (Upstream Reach), which includes the Upstream Reference Reach; at the I-5 crossing (Project Reach); and downstream of I-5 (Downstream Reach), which includes a low-gradient Downstream Design Reach (Figure 9 and Figure 26).

Upstream Reach

The Upstream Reach begins at the logging road culvert (931904) and extends downstream to the Project Reach. Data collection focused on the Upstream Reference Reach (also referred to herein as the Reference Reach), which starts approximately 100 feet upstream (west) of the I-5/Lake Samish Road interchange and extends upstream for approximately 375 feet. The Reference Reach was selected because of its location outside of the influence of the I-5/Lake Samish Road interchange and barriers and because of its natural forested and riparian conditions. The slope in the Reference Reach is approximately 8.1 percent. The Reference Reach is discussed in detail in Section 2.8.1.

Project Reach

The Project Reach extends from Culvert 995236 downstream to Culvert 995245 and consists of the six culverts at the I-5/Lake Samish Road interchange.

Downstream Reach

The Downstream Reach extends from the end of the Project Reach to approximately 150 feet downstream of Barleen Road (Figure 9). The Southern Tributary runs along Barleen Road, through the private culvert (931905) under Barleen Road, and then through a lower-gradient Downstream Design Reach (also referred to as the Design Reach), which is discussed in detail in Section 2.8.1. The private culvert is zero percent passable with the reason listed as slope (4.10 percent) by WDFW (2011c).

2.7.1 Data Collection

Data collection in the Upstream, Project, and Downstream Reaches was completed during the site reconnaissance visit on January 27, 2021 (Figure 9). The stream survey extended from the logging road culvert (931904), which is upstream of the Reference reach, downstream to the culvert at Barleen Road, (931905) approximately 2,600 feet; however, data were collected beyond the downstream extent of the survey. Data collection included 14 BFW measurements and six pebble counts. Observations were documented for channel geometry and stability, channel migration, vegetation conditions, instream woody material, and areas of aggradation and degradation. Field conditions are described in the Hydraulic Field Report Form (attached as Appendix B). Additional field data were collected on February 4, 2022.

Field observations and data collection are summarized below for the Upstream Reach (including the Reference Reach), Project Reach, and Downstream Reach (which includes a low-gradient Design Reach). Field data were used to describe and characterize the existing site conditions included in Section 2.7.2 (Existing Conditions) and Section 2.8 (Geomorphology).

Upstream Reach

Otak collected eight BFW measurements (BFW #1 through BFW #8) and three pebble counts (#1 through #3) in the Upstream Reference Reach. BFWs are described in detail in Section 56022416.439.56022416.439 (Channel Geometry). The on-site BFW concurrence meeting with WSDOT, the Lummi Nation, and WDFW occurred on April 28, 2021 (see Section 56022416.439.56022416.439). The co-managers concurred on the Reference Reach during that meeting.

Project Reach

Due to the continuous alignment of culverts at the I-5/Samish Road Interchange, there are limited extents of stream channel in this reach for the opportunity to collect stream data. However, one BFW measurement (BFW #9) was collected between Culverts 995232 and 995245 (between the I-5 northbound lanes and the northbound off-ramp lane at the I-5/Lake Samish Road interchange). Due to the altered channel conditions, no pebble counts were collected in the Project Reach.

Downstream Reach (Including Downstream Design Reach)

Two BFW measurements (BFW #10 and BFW #11) and two pebble counts (#4 and #5) were collected downstream of Culvert 995245 in the ditched reach of the South Tributary where it flows adjacent to Barleen Road.

Three BFW measurements (BFW #12 through BFW #14) and one pebble count (#6) were collected in the Downstream Design Reach, which is downstream of the private culvert under Barleen Road (931905). The Downstream Design Reach flows through a thick understory of vine maple (*Acer circinatum*) prior to flowing out into an open agricultural ditch and into Friday Creek.

2.7.1.2 Topographic Survey

The topographic survey was collected at the South Tributary culverts on December 1, 2020, (Culverts 995236 and 995235) and between January 21 and 27, 2021, (Culverts 995234, 995233, 995232, and 995245) by Otak. WSDOT provided the survey control for the site, and Otak set temporary control points in the field as needed. Survey data were collected using Trimble total stations (S6, S7, and SX10 versions). Due to the proximity of the numerous WSDOT injunction culverts in this area, the topographic surface was collected in the project area that extends approximately 150 feet west of Culvert 995236 (under the I-5 southbound on-ramp lane) to approximately 140 feet east of Culvert 995245 (downstream survey extent). The topographic surface was supplemented with light detection and ranging (LiDAR) data (USGS 2017) by WSDOT beyond the extents of the survey. The LiDAR data extended from approximately 650 feet west of the Culvert 995236 inlet to 400 feet east of the Culvert 995245 outlet.

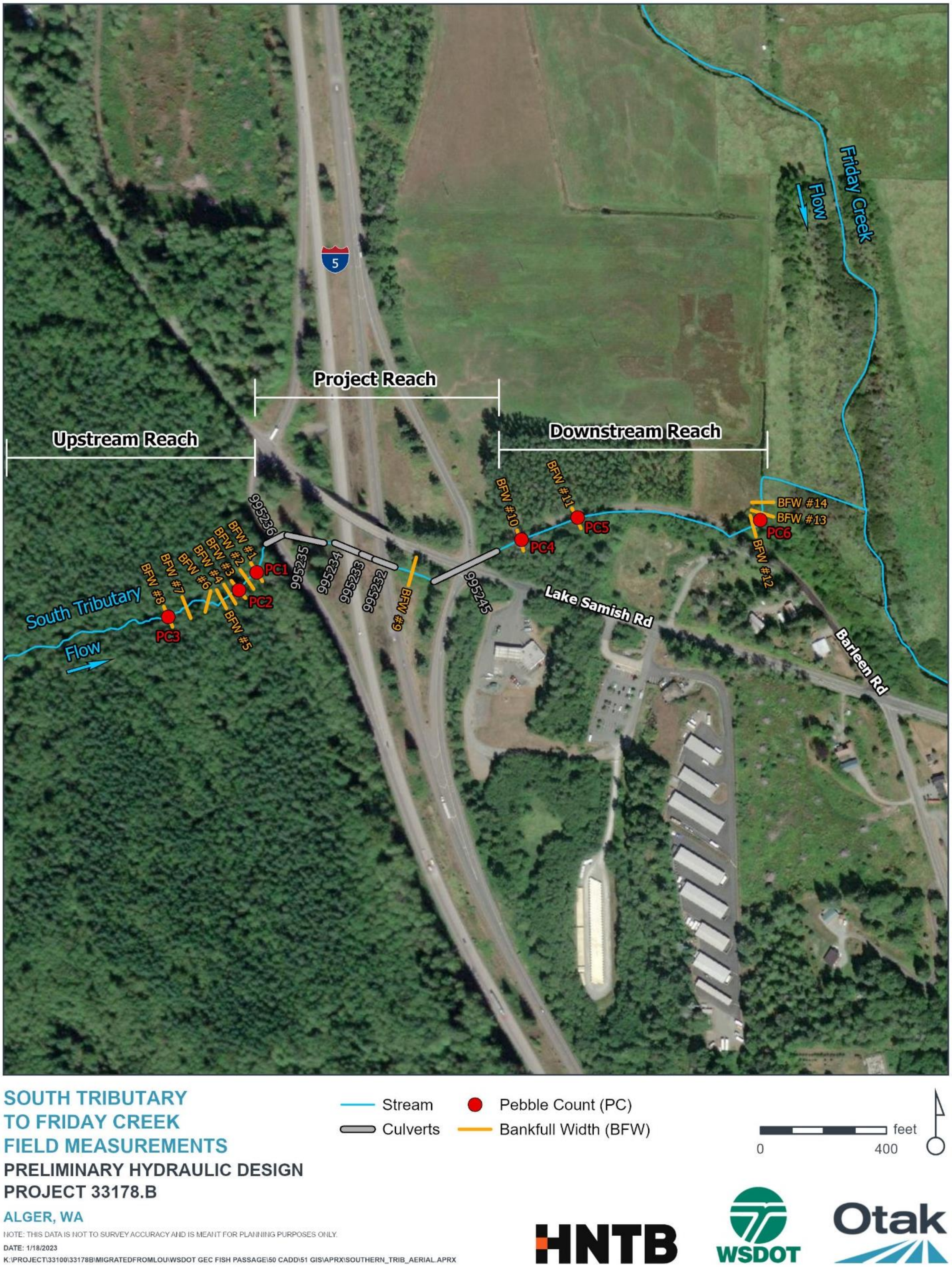


Figure 9: South Tributary Field Data Collection Locations

2.7.2 Existing Conditions

The existing conditions for the South Tributary WSDOT crossings (in the Project Reach) were documented by Otak during the site reconnaissance visit on January 27, 2021. The South Tributary project setting is described above in Section 2.4 (Site Description). The existing conditions are discussed from the upstream crossing to the downstream crossing at the I-5 interchange. The existing conditions in the Upstream Reach, Project Reach, and Downstream Reach are discussed in Section 2.8.1.

Culvert 995236

Culvert 995236 is a round precast concrete culvert, 52.8 feet in length and 2 feet in diameter, with a slope of 3.16 percent and 9.6 feet of fill (WDFW 2011d) (Figure 10 and Figure 11). This culvert conveys the South Tributary under the southbound on-ramp lane to I-5 along a steep grade. This culvert is the most upstream barrier in a continuous series of six fish-passage barriers at the I-5/Lake Samish Road interchange. No additional infrastructure features are in the project area.

Figure 10: Culvert 995236 Inlet

Figure 11: Culvert 995236 Outlet

The existing Culvert 995236 appears to be in fair to good condition. This culvert is located 104 feet downstream of the Upstream Reference Reach. At the outflow, the stream is daylighted for approximately 10 feet, then enters the next downstream culvert (995235). Vegetation near the culvert outlet consists of grasses and western swordfern (*Polystichum munitum*) with no canopy cover. Stream conditions immediately downstream are highly altered as the stream passes through the I-5 interchange in five additional downstream culverts. No sediment deposition or debris was noted at the culvert inlet. At the culvert outlet, there is a slight water surface drop of 0.3 foot. The culvert appears to be passing the stream's sediment load. Stream flow was observed during Otak's site visits in January 2021 and April 2021 upstream of Culvert 995236. There were no observations that the channel goes dry during the summer, so it was assumed there is consistent flow in the stream throughout the year.

As-built designs are available for the I-5/Lake Samish Road interchange; however, no details regarding the culvert design are included. No obvious signs of recent maintenance were noted at the existing culvert, and no maintenance records were available.

Culvert 995235

Culvert 995235 is a round, corrugated-steel culvert, 167 feet in length and 2 feet in diameter, with a slope of 11.15 percent and 23.0 feet of fill (WDFW 2011e) (Figure 12 and Figure 13). This culvert conveys the South Tributary under the median between the southbound on-ramp lane and southbound I-5 lanes along a steep grade. The culvert is the second-most upstream barrier in a continuous series of six fish-passage barriers at the I-5/Lake Samish Road interchange. The outlet of Culvert 995236 is approximately 10 feet upstream of the culvert's inlet. This steep culvert conveys stream flows down the open area with limited tree cover between the I-5 on-ramp southbound lane and the I-5 southbound freeway lanes. No additional infrastructure features are in the project area. The culvert appears to be in fair condition. Per the WSDOT Culvert Inspection Report, the bottom of the culvert is rotting out on both ends (WSDOT 2021b). The culvert inlet is not blocked with sediment or debris, and the culvert appears to be passing the stream's sediment load. There is a 0.7-foot drop at the culvert's outlet (Figure 12).

Vegetation at the culvert's inlet consists of grasses and western swordfern with no canopy cover. Immediately downstream of this culvert's outlet, the stream flows into the next downstream culvert, 995234. Stream conditions immediately downstream are highly altered as the stream passes through the interchange in four additional downstream culverts. Vegetation at the culvert outlet consists of grasses and invasive blackberry (*Rubus* spp.) (Figure 13).

There is no documented fish use at the existing culvert (WDFW 2011e). Resident fish may be present upstream in the Reference Reach, but their use is not documented by WDFW (WDFW 2011d).

As-built designs are available for the I-5/Lake Samish Road interchange; however, no details regarding the culvert design are included. No obvious signs of recent maintenance were noted at the existing culvert, and no maintenance records were available.

Figure 12: Culvert 995235 Inlet

Figure 13: Culvert 995235 Outlet

Culvert 995234

Culvert 995234 is a round precast concrete culvert, 64.9 feet in length and 2 feet in diameter, with a 0.86percent slope and 1.6 feet of fill (WDFW 2011f) (Figure 14 and Figure 15). This culvert conveys the South Tributary under the southbound I-5 lanes. This culvert is the third barrier in a continuous series of six fish-passage barriers at the I-5/Lake Samish Road interchange. This culvert is located at the grade break between the steep upstream culvert (995235) and the flatter grade under the I-5 southbound lanes. No additional infrastructure features are in the project area.

The culvert appears to be in fair to good condition. Vegetation at the culvert outlet consists of grasses with no canopy cover. The culvert inlet is not blocked with sediment or debris, and the culvert appears to be passing the sediment load. There is no water surface drop at the culvert outlet. Immediately downstream of this culvert, the stream flows into the next culvert, 995233.

There is no documented fish use at the existing culvert (WDFW 2011f). Resident fish may be present in the Upstream Reference Reach, but their use is not documented by WDFW (WDFW 2011f).

As-built designs are available for the I-5/Lake Samish Road interchange; however, no details regarding the culvert design are included. No obvious signs of recent maintenance were noted at the existing culvert, and no maintenance records were available.

Figure 14: Culvert 995234 Inlet (and Culvert 995235 Outlet)

Figure 15: Culvert 995234 Outlet

Culvert 995233

Culvert 995233 is a round corrugated-steel culvert, 44.9 feet in length and 2 feet in diameter, with a 6.11 percent slope and 9.6 feet of fill (WDFW 2011g) (Figure 16 and Figure 17). The culvert's steep slope prevents upstream fish passage through the structure (WDFW 2011g). This culvert conveys the South Tributary through the grassy median between the northbound and southbound lanes of I-5. The culvert is the fourth fish-passage barrier in a continuous series of six barriers at the I-5/Lake Samish Road interchange. No additional infrastructure features are in the project area. The culvert appears to be in fair condition. Per the WSDOT Culvert Inspection Report, both ends of the culvert are rotting away (WSDOT 2021d).

The culvert inlet is not blocked with sediment or debris. However, there is some gravel deposition at the culvert's outlet, the extent between the culvert outlet and inlet of Culvert 995232 has filled in with sediment, and the inlet to Culvert 995232 has filled in (Figure 17). A photo taken in 2011 by WDFW as part of its Level A Culvert Assessment (WDFW 2011g) does not show this deposition or infilling between Culverts 995233 and 995232 (Figure 18).

Vegetation at the culvert inlet and outlet consists of mostly grass with no canopy cover.

There is no documented fish use at the existing culvert (WDFW 2011g). Resident fish may be present in the Upstream Reference Reach, but their use is not documented by WDFW (WDFW 2011g).

As-built designs are available for the I-5/Lake Samish Road interchange; however, no details regarding the culvert design are included. No obvious signs of recent maintenance were noted at the existing culvert, and no maintenance records were available.

Figure 16: Culvert 995233 Inlet

Figure 17: Culvert 995233 Outlet (and Culvert 995232 Outlet) with Deposition

Figure 18: Culvert 995233 Outlet (and Culvert 995232 Outlet) showing a Water Surface Drop and no Deposition (photo taken in 2011 by WDFW)

Culvert 995232

Culvert 995232 is a round precast concrete culvert, 73.1 feet in length and 2 feet in diameter, with a slope of 1.66 percent and fill of 13.1 feet (WDFW 2011h) (Figure 19). This culvert is the fifth barrier in a continuous series of six fish-passage barriers at the I-5/Lake Samish Road interchange, and it conveys the South Tributary under the northbound I-5 lanes. No additional infrastructure features are in the project area. The culvert appears to be in poor to fair condition. This culvert is located at the grade break between the steep upper reaches and flatter valley bottom.

The culvert's inlet is partially blocked with sediment. The culvert's outlet is almost completely blocked with sediment and mostly submerged under water as a result of the sediment deposition in the channel at the outlet (Figure 20). Per the WSDOT Culvert Inspection Report, the culvert is blocked with sediment along its extent and the downstream ditch is full of sediment (WSDOT 2021e). This sediment blockage is a barrier that prevents fish passage through the structure. This condition was present in 2011 during WDFW's Level A Culvert Assessment (WDFW 2011g) (Figure 21).

Downstream of this culvert, the stream flows for approximately 130 feet in an open channel before flowing into the next downstream culvert, 995245. Vegetation near the culvert's inlet and outlet consists mostly of grass with no canopy cover.

The downstream culvert (995245) blocks upstream anadromous fish passage to the site. There is no documented fish use at the existing culvert (WDFW 2011h). Resident fish may be present in the Upstream Reference Reach, but their use is not documented by WDFW (WDFW 2011h).

As-built designs are available for the I-5/Lake Samish Road interchange; however, no details regarding the culvert design are included. No obvious signs of recent maintenance were noted at the existing culvert. Based on information directly from WSDOT staff, the southern tributary had 15 cubic yards removed from the outlet side in 2018 (Case, personal communication, April 21, 2021).

Figure 19: Culvert 995232 Inlet (and Culvert 995233 Outlet)

Figure 20: Culvert 995232 Outlet

Figure 21: Culvert 995232 Outlet showing Sediment Deposition and Submerged Culvert Conditions (photo taken in 2011 by WDFW)

Culvert 995245

Culvert 995245 is a round precast concrete and steel culvert, 228.6 feet in length and 2.5 feet in diameter, with a slope of 2.73 percent and 23 feet of fill (WDFW 2011a) (Figure 22 and Figure 23). The upstream end is precast concrete, and the downstream end is steel. The culvert outlet is perched with a water surface drop of 1.4 feet (as reported by WDFW 2011a). This culvert is the sixth and most downstream barrier in a continuous series of six fish-passage barriers at the I-5/Lake Samish Road interchange and conveys the South Tributary under the northbound I-5 on-ramp lane at the interchange. No additional infrastructure features are in the project area. The culvert appears to be in poor to fair condition. Three pebble counts were collected downstream of this culvert (see Section 2.8.3, Sediment).

This culvert is a barrier to upstream fish passage. Coho salmon fry were observed by WDFW downstream of the site (WDFW 2011a). Resident fish may be present in the Upstream Reference Reach, but their use is not documented by WDFW (WDFW 2011a).

As-built designs are available for the I-5/Lake Samish Road interchange; however, no details regarding the culvert design are included. No obvious signs of recent maintenance were noted at the existing culvert, and no maintenance records were available for this culvert.

Figure 22: Culvert 995245 Inlet

Figure 23: Culvert 995245 Outlet

Culvert near I-5 MP 240.86

The culvert near I-5 MP 240.86 is a 2-foot diameter, 300-foot-long concrete pipe that crosses I-5 approximately 300 feet south of Culvert 995236. The culvert inlet and outlet are shown, respectively, in Figure 24 and Figure 25. The culvert pipe connects to several storm drain structures. The culvert conveys runoff from the ditch and hill slope west of I-5 to the median east of I-5, upstream of the inlet to Culvert 995245. The flows conveyed by the culvert are not a mapped stream in the WDFW SWIFD. The culvert is not identified as a fish-barrier by WDFW.

Figure 24: Inlet of Culvert near I-5 MP 240.86

Figure 25: Outlet of Culvert near I-5 MP 240.86

2.7.3 Fish Habitat Character and Quality

2.7.3.1 Upstream Reach

The forested stream habitat above the I-5/Lake Samish Road interchange is in a steep ravine that has been logged within the last 40 years. In this reach, the South Tributary habitat characteristics include step-pools, riffles, moderate cobbles, and fines that can support resident fish spawning and rearing habitat. (See Section 2.8 and Appendix B, Hydraulic Field Report Form.)

Prior to the construction of I-5, the South Tributary may have meandered in an alluvial channel downslope and through the floodplain area and extensive wetlands prior to entering Friday Creek. The wetland areas adjacent to Friday Creek have been channelized for agriculture purposes and have remained ditched in the years since. Habitat channel conditions below the project site are predominantly agricultural ditches.

The quality of fish habitat above the I-5/Lake Samish Road interchange crossings could support resident and anadromous fish life due to presence of spawning gravels, numerous pools formed by medium to large boulders, overhanging native vegetation, and fallen large woody material (LWM). The South Tributary is well-shaded and has a forested riparian buffer. The South Tributary can likely maintain water temperatures suitable for a variety of life stages.

Due to the quality of spawning and rearing habitat above the I-5 interchange, it is likely that resident and anadromous fish species may use this reach for spawning and rearing if the downstream barrier culverts were removed and stream gradients are accessible. For the South Tributary, habitat gains of up to 4,200 linear feet could be made for non-anadromous species if the I-5 culvert barriers were replaced (Table 5). However, according to the SWIFD and FPDSI, no fish species have been documented above the I-5/Lake Samish Road interchange.

No juvenile or adult fish were seen during the January 2021 site visit conducted by Otak. Fish presence data in this report are only confirmed for Friday Creek with the exception of juvenile coho salmon downstream of Culvert 955245 (as documented by WDFW [2011a]). The lower reaches of the South Tributary may support rearing habitat.

2.7.3.2 Project Reach

Due to the absence of spawning gravels in the I-5 median or the downstream channelized stream portions, viable rearing or spawning habitat is not identified within the Project Reach due to lack of flow, habitat cover, and spawning bed material. The Project Reach is disconnected from the Upstream and Downstream Reaches by a series of corrugated metal pipes (project culverts) and overall lacks in-channel wood, pools, sediment, and gravels. Pipe gradient slopes and drops within this reach are identified as barriers for fish passage by WDFW (WDFW 2011a, 2011d , 2011e, 2011f, 2011g, 2011h).

2.7.3.3 *Downstream Reach*

The South Tributary downstream of the I-5 interchange is ditched for approximately 800 feet along Barleen Road. Beginning at Culvert 995245, sparse riparian habitat is composed of western redcedar (*Thuja plicata*), salmonberry *(Rubus spectabilis*), red elderberry (*Sambucus racemosa*), and other native species as well as invasive species such as blackberry and reed canarygrass (*Phalaris arundinacea*).

Downstream of Culvert 931905, the stream widens and occupies a straight channel that makes a right angle turn prior to its confluence with Friday Creek. This lower section of the South Tributary has likely been affected by agricultural, residential, and forestry land uses. Based on its straight channel alignment and nearby agricultural ditches, the stream has likely been straightened and ditched.

It is unclear of the extent that the reach downstream of I-5 and adjacent to Barleen Road can support fish life in its present form. Juvenile fish have been observed by WDFW below Culvert 995245 (WDFW 2011h), but no spawning habitat has been identified within the Project Reach. Potential limitations to supporting fish life in this reach include the lack of floodplain connectivity, lack of sediment supply, and lack of riparian cover.

2.7.3.4 *Friday Creek*

Friday Creek is classified as a salmon-bearing tributary to the Samish River. Eight species of anadromous and resident fish have been documented or are presumed to be present within this system in the vicinity of the confluence of the South Tributary (WDFW 2020a, 2020b) (). Friday Creek is the largest tributary to the Samish River. Friday Creek originates from Lake Samish, flows south through agriculture lands, and reaches the Samish River 5 miles south of Alger. Identified limiting factors (poor rating) in Friday Creek are fish passage, floodplain conditions, road density, sediment conditions (gravel quantity), riparian conditions, and water quality (Smith 2003). In addition, data gaps were identified for the following limiting factors: sediment gravel quality, stream bed stability, instream LWM and water quantity (Smith 2003).

2.7.3.5 *South Tributary Habitat Gains*

Beginning at Culvert 995245, up to 4,200 linear feet of habitat gain may have potential for fish passage if stream simulation culverts were installed through the Project Reach (WDFW 2011a) (Table 5). No anadromous or resident fish have been documented in the stream above the I-5/Lake Samish Road interchange culverts (WDFW 2020a, 2020b).

Table 5: South Tributary Summary of Habitat, Spawning, and Rearing Gains

Culvert ID	Barrier Reason	Slope (%)	Habitat Gain (feet)	Spawning Habitat Gain (ft^2)	Rearing Habitat Gain (ft^2)	Priority Index (PI)
995236	Slope	3.16	3,660.5	4,207.2	9,447.3	5.91
995235	Slope	11.15	3,713.0	4,207.2	9,447.3	6.53
995234	Velocity	0.86	3,883.5	4,217.9	9,479.6	5.43
995233	Slope	6.11	3,952.4	4,217.9	9,490.3	6.55
995232	Slope	1.66	4,001.6	4,228.7	9,501.1	5.92
995245	WSE Drop	2.73	4,209.3	4,540.7	9,974.5	6.62

Sources: WDFW 2011a, 2011d, 2011e, 2011f, 2011g, 2011h

2.8 Geomorphology

Each of the following sub-sections (e.g., Reference Reach Selection, Channel Geometry, Sediment) includes a discussion of geomorphology for the Upstream Reach (includes the Upstream Reference Reach), Project Reach (culverts at I-5/Lake Samish Road interchange), and Downstream Reach (includes a Downstream Design Reach).

Because the South Tributary includes multiple grades along its alignment, field information from the Upstream Reference Reach and Downstream Design Reach were used to guide the proposed streambed design (Section 5). This approach is further described in Section 2.8.1 (Reference Reach Selection).

2.8.1 Reference and Design Reach Selection

Upstream Reference Reach

An Upstream Reference Reach for the South Tributary was selected west (upstream) of the I-5/Lake Samish Road interchange (Figure 26). This Reference Reach was used to guide the design for the higher-gradient design reaches (4 to 8 percent) where step-pool morphologies will be the predominant channel morphology. Based on the Montgomery and Buffington (1997) classification system, stream channels with slopes in the range of 4 to 8 percent support step-pool morphologies. This was confirmed by Otak's field observations in the Upstream Reference Reach.

The Reference Reach is located approximately 100 feet upstream (west) of Culvert 995236 and the southbound on-ramp lane to I-5 at the interchange, and extends for approximately 375 feet upstream. This upstream area west of I-5 was selected as the Reference Reach because it is located outside the influence of the fish-passage barriers and the I-5/Lake Samish Road interchange. The area was logged between 1976 and 1981 but has since revegetated with a forest stand mostly of conifers approximately 40 to 45 years of age. The Reference Reach is a high functioning and relatively natural channel with high quality fish habitat, an intact riparian corridor, and dense understory vegetation, and an existing upstream culvert (931904) does not appear to substantially alter the flow and sediment regimes.

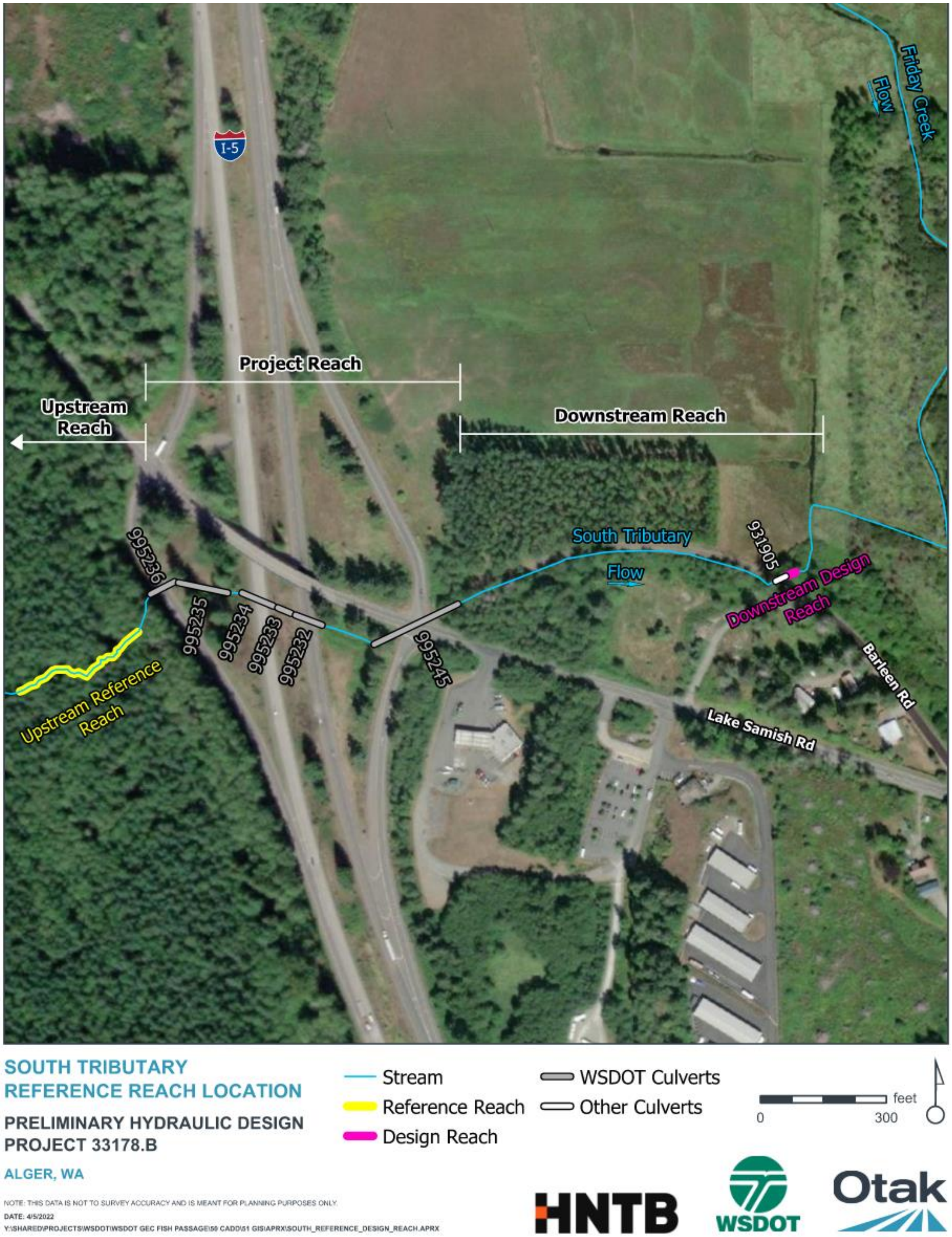


Figure 26: South Tributary Upstream Reference Reach and Downstream Design Reach Locations

A site reconnaissance of the Upstream Reference Reach was conducted on January 27, 2021, under cool, wet weather conditions. The Reference Reach is accessed from the on-ramp to southbound I-5 at the I-5/Lake Samish Road interchange (Figure 26). Along this reach, the stream flows within a forested, moderately steep, confined valley with a limited overbank floodplain (Figure 27). A young to mature alder riparian corridor is present with well-established understory vegetation. The gradient at the Reference Reach is 8.1 percent, while the gradient downstream of I-5 is approximately 1.4 percent. The grade flattens out to 0.1 percent downstream of Barleen Road in the wetland area near the confluence with Friday Creek. This is a forested area with an intact riparian corridor and limited anthropogenic influence.

The channel morphology consists of forced step-pool and step-pool morphology with some riffles (Figure 28). Pools found within the Reference Reach are mainly associated with the forced step-pool and step-pool morphology. This reach can be characterized as a transport reach.

Upstream stream conditions could support anadromous fish use, but the slope and downstream barriers block access. There is no documented fish use at the existing culvert (WDFW 2011d). Resident fish may be present upstream in the Reference Reach, but their use is not documented by WDFW.

Figure 27: View of the South Tributary Reference Reach Located Upstream of Culvert 995236, Looking Upstream (west)

Figure 28: Typical Reference Reach Channel Morphology, View Looking Upstream (west)

Otak completed measurements of the in-channel step-pool features in the Upstream Reference Reach on February 4, 2022. Six step-pools were measured in the Reference Reach, and a summary of the measurements is shown in Table 6. The stationing for the step-pools is based on the distance upstream of the Culvert 995236 inlet. Step heights and spacing between the steps were documented. The observed steps had an average height of 1.3 feet and average spacing of 15.7 feet (between each step). The primary step-forming mechanisms are a few stable boulders, with large cobbles and small woody material wedged behind the boulders to form each step. Water depths immediately downstream of the steps ranged from 0.3 to 1.0 foot. A typical step-pool within the Upstream Reference Reach is shown in Figure 29.

Table 6: Summary of Step-Pool Measurements Within Upstream Reference Reach

Step #	Station* (feet)	Spacing (feet)	Height/Drop (feet)	Wetted Width (feet)
1	124	18	1.6	3.7
2	142	18	2.0	3.7
3	151	9	0.6	5.0
4	163	12	0.6	5.0
5	178	15	1.5	5.2
6	200	22	1.4	3.8
Average	N/A	15.7	1.3	4.4

*Distance measured upstream of existing Culvert 995236 Inlet

Figure 29: Typical Step-Pool Within Upstream Reference Reach

Downstream Design Reach

Downstream of the Reference Reach, the stream channel is conveyed through a series of six fish-passage barriers at its crossing under the I-5/Lake Samish Road interchange. East of I-5, the stream flows through a channelized section adjacent to Barleen Road, and to a private culvert (931905) crossing under Barleen Road. This downstream reach, with its highly altered channel geometry, bank and riparian conditions, and flat grade (Figure 30), was not a suitable design reach for the upstream reaches. The private Culvert 931905 is identified on the WDFW Culvert Inventory as a fish-passage barrier, zero percent passable (WDFW 2011c). Downstream of Culvert 931905, the South Tributary flows through agricultural ditches and wetlands out to Friday Creek. Because of the low-gradient of the stream downstream of Culvert 931905, the reach serves as a reasonable design reach for the lower Project Reach (Culvert 995245) (Figure 31). The location of the Downstream Design Reach is shown in Figure 26.

Figure 30: View of the South Tributary Downstream of I-5 along Barleen Road, Looking Downstream (east)

Figure 31: South Tributary Design Reach Downstream of Barleen Road Culvert (931905)

The Downstream Design Reach (response reach) was used to guide the design for the lower-gradient reaches of the proposed design (Section 5). The Design Reach has a slope of 2.5 percent and is dominated by a riffle morphology with sporadic pools occurring at in-channel wood. This reach will provide guidance for the lower-gradient design reaches (less than 4 percent) of the stream design located downstream of I-5. Despite the fact that this reach experiences some impacts from the adjacent land use and the upstream Culvert 931905 at Barleen Road, it is still a close analog for stream considerations such as slope, streambed material, and hydrology. The Downstream Design Reach is too short and modified to provide accurate design conclusions on parameters such as stream planform or sinuosity. However, it was used for measuring BFW, bankfull depth, and streambed gradation (through pebble counts), all of which were used as a basis of design for proposed stream reaches with slopes less than 4 percent.

Reference and Design Reach Summary

The slopes at the existing site consist of a steep upper reach above I-5 (approximately 8 percent), a very steep reach at the I-5 crossing (approximately 13 percent), and a low-gradient reach (2.5 percent to 1.4 percent) east of I-5. To guide the design for the proposed reaches with these slopes, the project designs will be based on the Upstream Reference Reach, the Downstream Design Reach, and the Montgomery and Buffington classification system for stream channels (Montgomery and Buffington 1997) (Table 7). Stream sections having slopes of 1 to 2 percent will be designed with a pool-riffle morphology, stream sections having slopes of 2 to 4 percent will be designed with sufficient channel complexity to ensure a forced riffle pool morphology (see Section 4.4.4) , and stream sections with slopes of greater than 4 percent will have a step-pool morphology (similar to the Upstream Reference Reach. Large wood will be incorporated into the stream design for stream lengths located outside of the crossing structures (see Section 5, Streambed Design).

Table 7: Reference and Design Reach Channel Morphology Categories (by slope)

Stream Design Slope Category (or Bin?)	Channel Morphology	Basin Reference	Design Literature Reference
3–8%	Step-Pool, Forced Step-Pool	Upstream Reference Reach	Montgomery and Buffington (1997)
2–3%	Plane-Bed Riffle	Channel slope along a natural channel not available in-basin	Montgomery and Buffington (1997)
1–2%	Pool-Riffle	Downstream Design Reach (d/s of Barleen Road)	Montgomery and Buffington (1997)

Note: See Section 5, Streambed Design, for the proposed channel depths and widths for each stream slope category.

2.8.2 Channel Geometry

The South Tributary is a single-thread channel that extends approximately 7,200 feet from its headwaters in the foothills west of the project site (approximate elevation of 600 feet) downstream to its confluence with Friday Creek near the town of Alger (an approximate elevation of 245 feet). As noted in Section 2.7, the stream can be subdivided into three reaches: the Upstream Reach, which includes the Upstream Reference Reach, the Project Reach through the I-5/Lake Samish Road interchange area, and the Downstream Reach, which includes the Downstream Design Reach.

In the Upstream Reach, the stream flows within a forested, moderately steep, confined valley, with a limited overbank floodplain. In the Reference Reach, the stream has a narrow floodplain with an approximate 8.1 percent overall channel slope. The stream flows out of its forested valley into the Project Reach, where it flows through a series of six fish-passage barriers under the I-5/Lake Samish Road interchange. The slopes along this reach range from 1.6 to 13.0 percent (based on the topographic survey). The second most upstream culvert (995235) has the highest slope of 13.0 percent; this culvert conveys flows under the open area between the I-5 south on-ramp and the I-5 southbound lanes. East of Barleen Road in the Downstream Reach, the stream enters an approximately 100-foot-long reach with approximately 2.5 percent slope, and then flows into the floodplain of Friday Creek where the stream gradient is much lower, approximately 0.1 percent. Throughout the Downstream Reach, the channel is highly altered and flows within a series of constructed ditches before draining into Friday Creek. The floodplain along the Downstream Reach is much wider than in the Upstream Reach due to its low slope and lack of valley confinement. The stream channel extends for approximately 1,375 feet downstream of I-5 where it enters Friday Creek just northeast of Barleen Road.

Otak measured a total of 14 BFWs at the project site (Figure 32). Twelve BFWs were measured on January 27, 2021: eight within the Upstream Reference Reach (BFW #1 through BFW #8); one within the Project Reach, between the I-5 northbound lanes and the off-ramp between Culverts 995232 and 995245 (BFW #9); and three within the Downstream Reach (BFW #10 through BFW #12). Representative cross sections for each of these three reaches are presented in Figure 33 and Figure 34. Two additional BFW measurements were collected on February 4, 2022, downstream of Barleen Road in the Downstream Design Reach (BFW #13 and BFW #14).

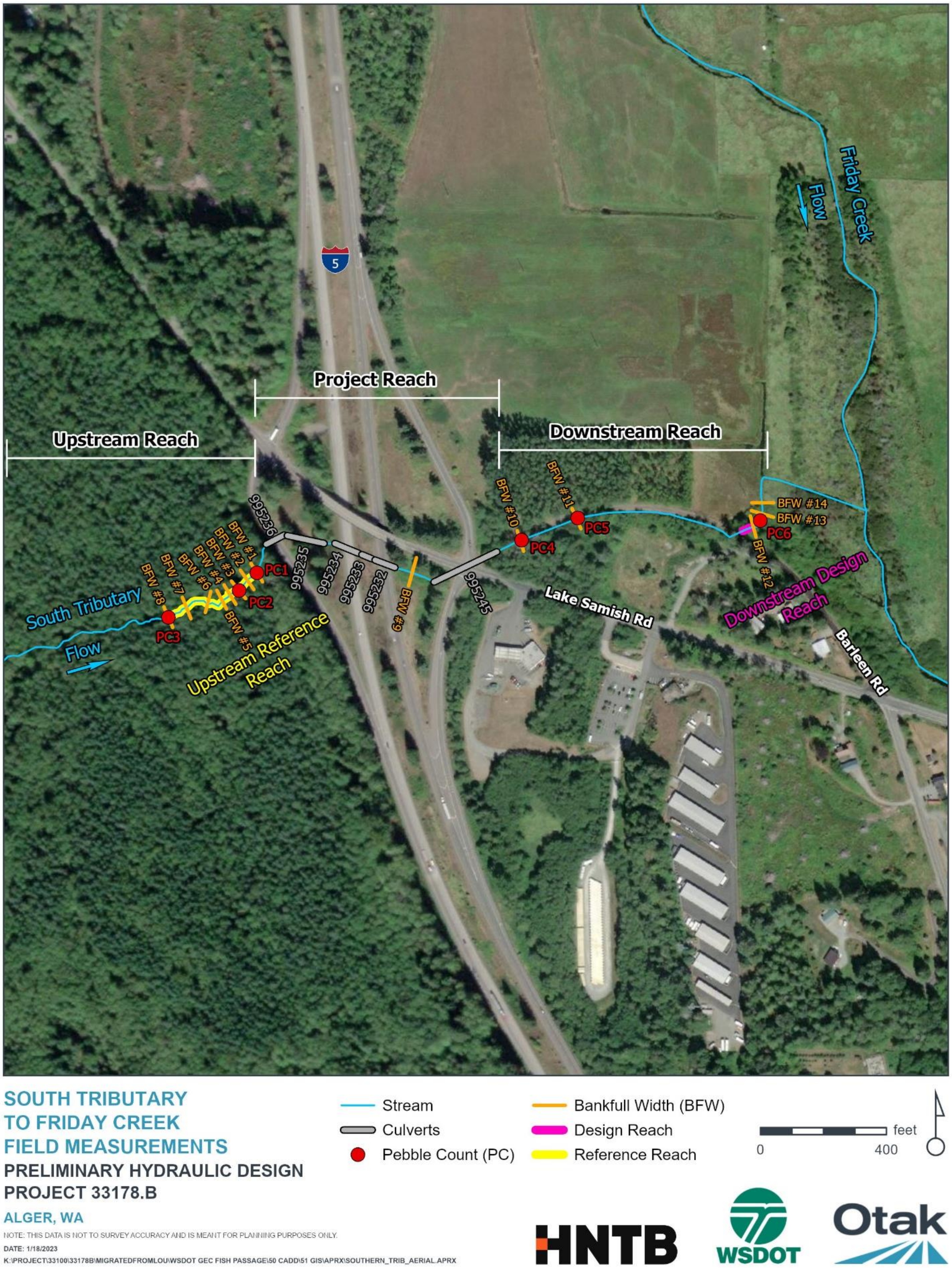


Figure 32: Measurement Locations

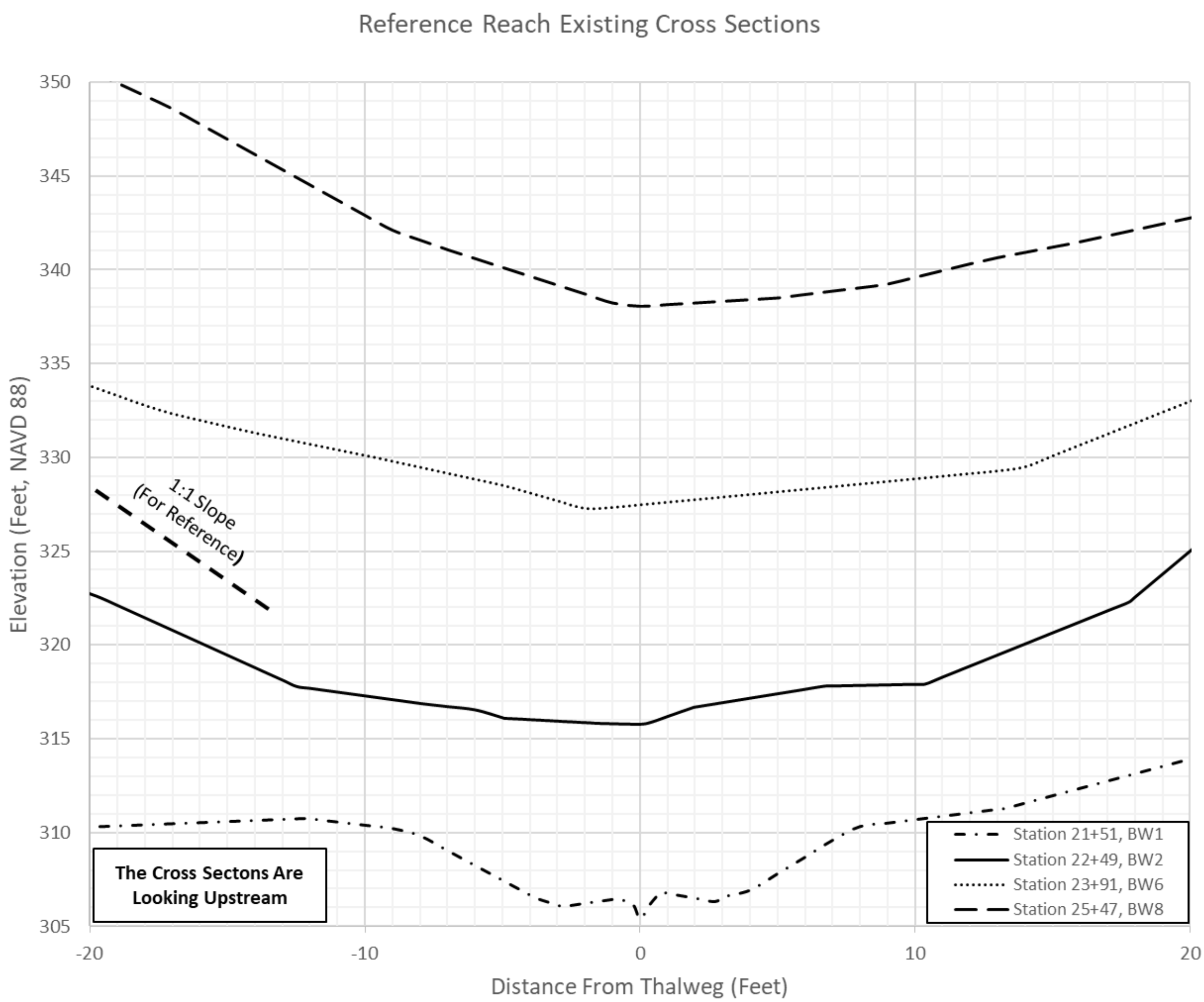


Figure 33: South Tributary Reference Reach Existing Cross Sections

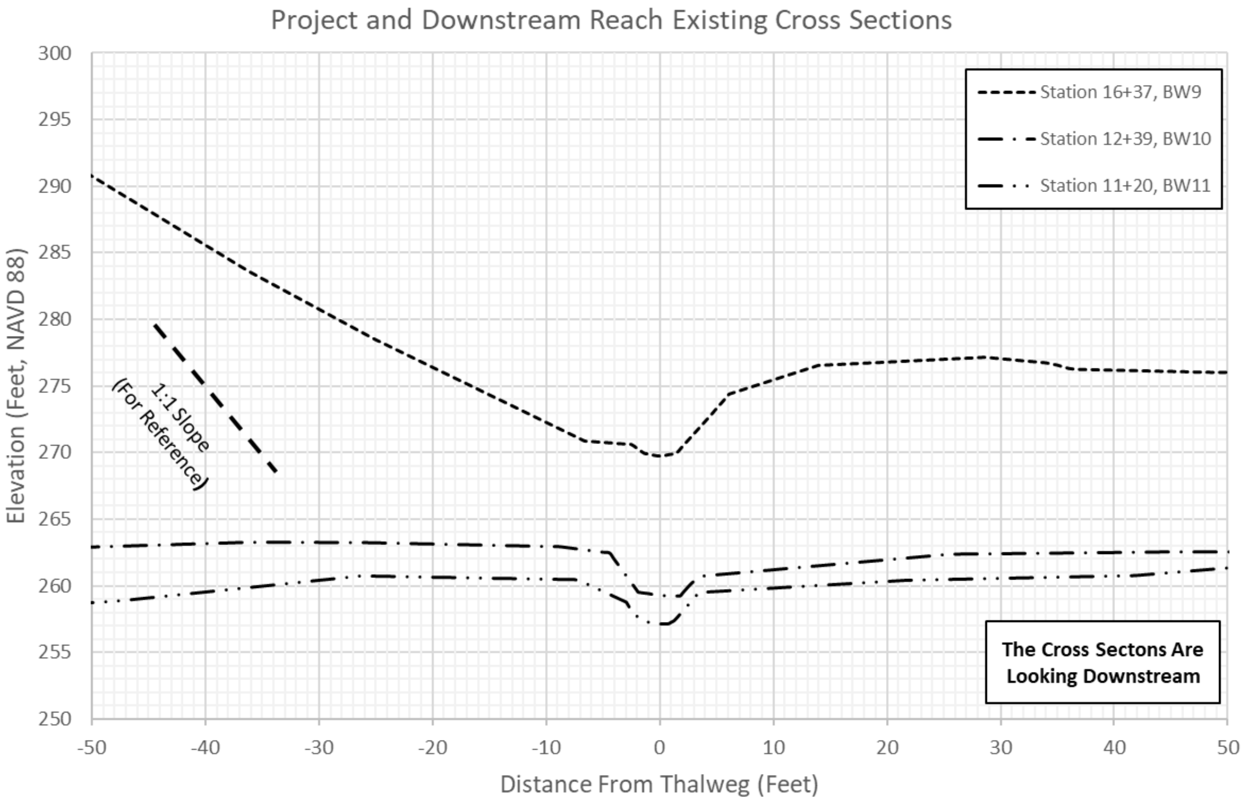


Figure 34: South Tributary Existing Cross Sections (in Project Reach and Downstream Reach)

Upstream Reach

Eight BFWs were field measured by Otak on January 27, 2021 (Figure 32 and Table 8) in the Upstream Reference Reach. The average of those BFW measurements was 7.8 feet (Figure 35 through Figure 43). The width-to-depth ratio ranged from 3.4 to 6.6 feet. The channel cross section is generally trapezoidal, influenced locally by the presence of large wood and step-pool morphology. The channel has a steep average slope of 8.1 percent and is confined by hillslopes on both sides with a narrow floodplain. The channel is slightly entrenched and has a sinuosity of 1.05 through the Reference Reach.

Per the stream evolution model stage characterization, the Upstream Reach can be generally characterized as Stage 1, sinuous, single-thread (Cluer and Thorne 2014). However, due to the steep slope, valley confinement, and relative erodibility of the channel margins, the channel has a low sinuosity. Further with the limited anthropogenic disturbances within this reach supports the Stage 1 classification. Cluer and Thorne (2014) is more applicable to alluvial channels undergoing disturbance, whereas the Reference Reach is relatively undisturbed with a stable channel planform with colluvial inputs.

Table 8: South Tributary Bankfull Width Measurements Collected in Upstream Reference Reach

BFW #	Width (feet)	Included in Design Average?	Location Measured (feet upstream of Culvert 995236)	Concurrence Notes
1	9.6	Yes	104	Comanagers concurred on 4/28/2021
2	8.3	Yes	164	Comanagers concurred on 4/28/2021
3	8.3	Yes	225	Comanagers concurred on 4/28/2021
4	7.5	Yes	256	Comanagers concurred on 4/28/2021
5	7.9	Yes	288	Comanagers concurred on 4/28/2021
6	8.7	Yes	319	Comanagers concurred on 4/28/2021
7	6.5	Yes	397	Comanagers concurred on 4/28/2021
8	5.7	Yes	475	Comanagers concurred on 4/28/2021
Reference Reach Design Average[a]	7.8			

Note:

a. Average calculated from measurements collected within the Upstream Reference Reach.

Figure 35: Bankfull Width #1

Figure 36: Bankfull Width #2

Figure 37: Bankfull Width #3

Figure 38: Reference Reach Bankfull Width #4, Looking Upstream

Figure 39: Reference Reach near Bankfull Width #4, Looking Downstream

Figure 40: Bankfull Width #5

Figure 41: Bankfull Width #6

Figure 42: Bankfull Width #7

Figure 43: Bankfull Width #8, View Looking Upstream

Project Reach (I-5/Lake Samish Road Interchange)

The stream flows through an almost continuous alignment of six fish-passage barriers at the I-5/Lake Samish Road interchange. One stream reach is daylighted between the two most downstream culverts, 995232 and 995245 where it flows within a grass- and blackberry-lined ditch having a general trapezoidal shape (Figure 34). The BFW measured along this stream reach (BFW #9) was 7.3 feet with a depth of 1.5 feet with a width-to-depth ratio of 4.9 feet (Table 9 and Figure 44Figure 34). Due to its conveyance through a series of six culverts in this reach and limited open channel alignment, the stream's sinuosity and channel evolution stage are not characterized (for this reach).

Table 9: South Tributary Bankfull Width Measurements Collected in Project Reach and Downstream Reach

BFW #	Width (feet)	Included in Downstream Design Average?	Location Measured (feet upstream/downstream of Culvert 995245)	Concurrence Notes
9	7.3	No	70 feet upstream	Collected in Project Reach (at I-5)
10	8.5	No	50 feet downstream	Collected in Downstream Reach
11	9.3	No	200 feet downstream	Collected in Downstream Reach
Project and Downstream Reach Average	8.9			

Notes:

1. Average BFW used to inform the channel BFW along the lower-gradient channel (see Section 5).
2. Average does not include BFW #9 which is collected in the Project Reach between 995232 and 995245.

Figure 44: Bankfull Width #9 Between Culverts 995232 and 995245

Downstream Reach (Including Downstream Design Reach)

Two BFWs were measured downstream of the project site and upstream of Barleen Road. The BFW measurements were 8.1 feet and 9.3 feet (BFW average of 8.9 feet) and depths were 1.5 and 3.0 feet, resulting in width-to-depth ratios of 2.8 and 5.4 feet (Table 9). BFWs measured adjacent to Barleen Road were not used to inform the BFW for design due to the stream's altered state (Figure 45). Along this reach, the South Tributary flows within a ditch adjacent to Barleen Road that has a mostly trapezoidal shape (Figure 34 and Figure 46). In the valley near its confluence with Friday Creek, the stream's floodplain is much wider. Due to its highly altered condition and anthropogenic influences along its alignment adjacent to Barleen Road and through agriculture fields, the stream's sinuosity and channel evolution stage are not characterized.

Figure 45: Bankfull Width #10

Figure 46: South Tributary in Downstream Reach East of I-5, View Looking Downstream

Three BFW measurements were taken in the Downstream Design Reach, downstream of the Barleen Road culvert (931905) and upstream of the confluence with Friday Creek (Figure 32, Figure 47 through Figure 49, and Table 10). The BFWs ranged from 7.4 feet to 9.3 feet (average of 8.2 feet), and depths ranged from 1.0 foot to 1.1 feet, resulting in width-to-depth ratios ranging from 7.1 to 9.3. One pebble count was taken in the Downstream Design Reach to provide streambed material gradations to guide design of streambed materials for the stream channel at lower slopes.

Table 10: South Tributary Bankfull Width Measurements Collected in Downstream Design Reach

BFW #	Width (feet)	Included in Downstream Design Average	Location Measured (feet) (approx) Downstream of Barleen Road	Concurrence Notes
12	9.3	Yes	40 feet Downstream	Collected in Downstream Design Reach 2/4/22
13	7.8	Yes	65 feet Downstream	Collected in Downstream Design Reach 2/4/22
14	7.4	Yes	90 feet Downstream	Collected in Downstream Design Reach 2/4/22

BFW #	Width (feet)	Included in Downstream Design Average	Location Measured (feet) (approx) Downstream of Barleen Road	Concurrence Notes
Downstream Design Reach Average	8.2			

Figure 47: Bankfull Width #12, Within Downstream Design Reach

Figure 48: Bankfull Width #13, Within Downstream Design Reach

Figure 49: Bankfull Width #14, Within Downstream Design Reach

On-Site Bankfull Width Concurrence Meeting with Agencies and Tribes

The on-site BFW concurrence meeting was held April 28, 2021. This on-site meeting was preceded by a teleconference meeting on April 26, 2021, to share background BFW information with WSDOT, WDFW, Lummi Nation, Upper Skagit Indian Tribe, and Skagit River System Cooperative (comanagers).

During the on-site BFW concurrence meeting, Otak personnel met with the comanagers (representatives from WSDOT, WDFW, and Lummi Nation) to field verify the BFW measurements collected by Otak on January 27, 2021, and February 4, 2022. The comanagers verified BFW #1 (9.6 feet) and concurred that the BFW measurements collected by Otak are representative for the Upstream Reach with an overall average BFW measurement of 7.8 feet, and a range of 5.7 to 9.6 feet ().

Upstream Reference Reach Bankfull Width

Based on the BFW measurements agreed upon by the comanagers, the average BFW measurement is 7.8 feet, with a range of 5.7 feet to 9.6 feet. This average BFW was used to inform the minimum hydraulic opening of the preliminary water crossing structure design.

2.8.3 Sediment

Along the South Tributary, three pebble counts and substrate observations were taken in the Upstream Reference Reach and three were taken in the Downstream Reach, each at the approximate location of a BFW measurement (Figure 32). A gravelometer and the standard Wolman Pebble Count procedure using the zig-zag method were used for each pebble count.

Upstream Reach

In the Upstream Reference Reach, the bed substrate was assessed to be fine to coarse gravels, with cobbles and boulders, with a very low percentage of fines. The Upstream Reference Reach has an average D_{50} and D_{84} of 0.8 inch and 2.2 inches, respectively (Table 11) (Figure 50 through Figure 56). Sediment within the stream is mainly supplied by hillslope processes and local bank erosion. In addition, rootwads of fallen trees along the riparian corridor contribute sediment, including boulders, to the channel. Sporadic large boulders are present in the reach and measure up to approximately 26 inches in diameter (Figure 57 and Figure 58). These are often associated with the step-pools; however, random large boulders were noted throughout the reach. These boulders appear stable and are often covered in moss, indicating no recent movement.

Project Reach

No pebble counts were taken in the Project Reach because of the influence of the upstream and downstream culverts on the bed substrate and lack of adequate daylighting of the stream channel.

Downstream Reach (including Downstream Design Reach)

Bed substrate in the Downstream Reach has an average D_{50} and D_{84} of 0.5 inch and 1.2 inches, respectively (Figure 59, Figure 60, Figure 61, and Table 12). The reach downstream of Culvert 995245 generally lacks large boulders (Figure 46).

The Downstream Design Reach has an average D_{50} and D_{84} of 0.4 inch and 1.1 inches, respectively (Figure 62, Figure 63, Figure 64 and Table 13). The Design Reach generally lacks large boulders with the channel dominated by sand and gravel-sized sediment.

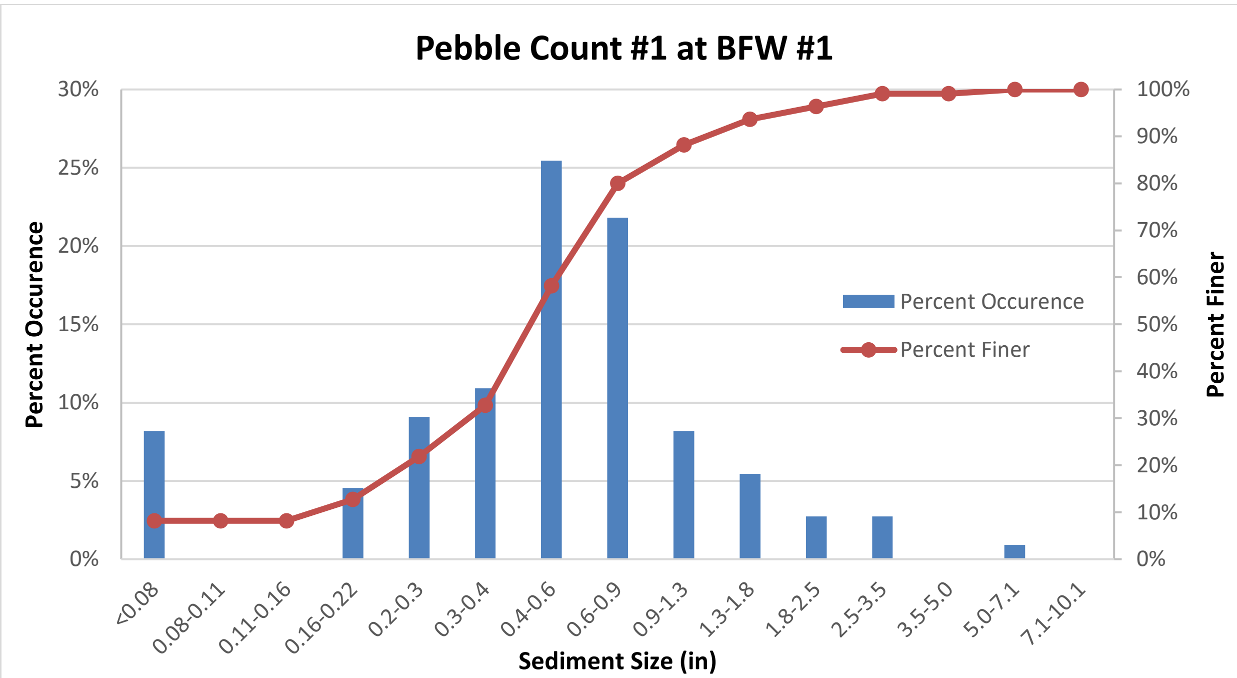


Figure 50: Pebble Count #1

Figure 51: South Tributary Reference Reach Pebble Count #1

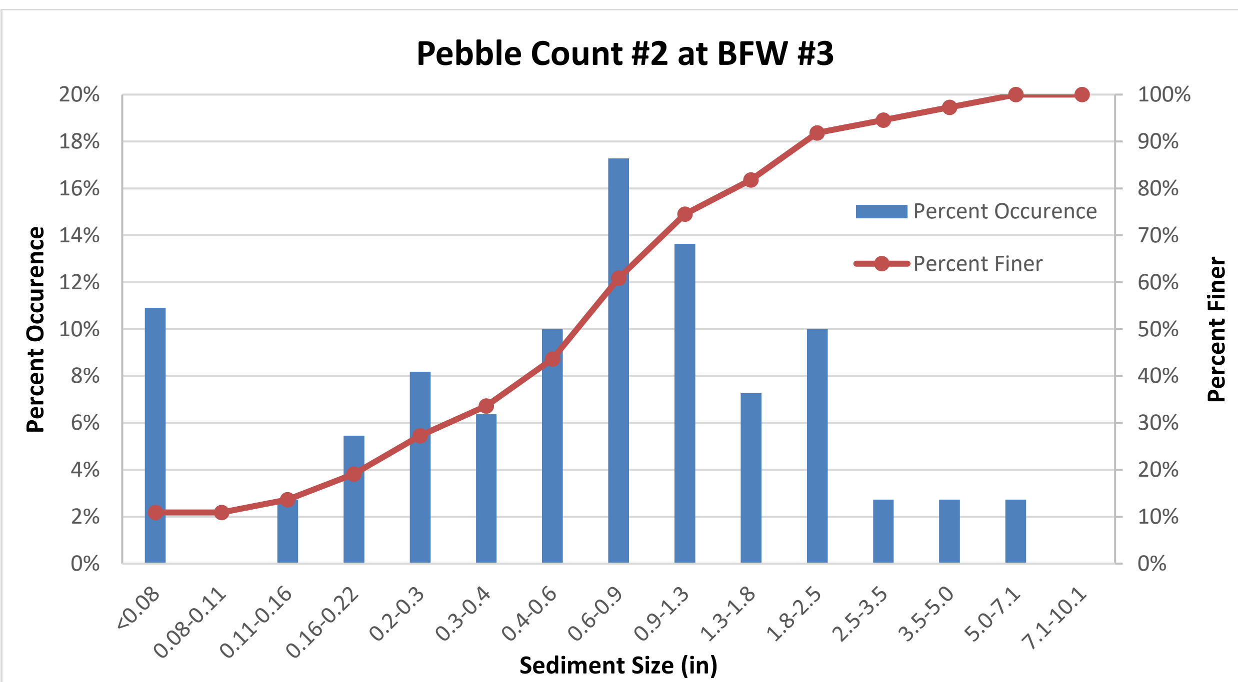


Figure 52: Pebble Count #2

Figure 53: South Tributary Reference Reach Pebble Count #2

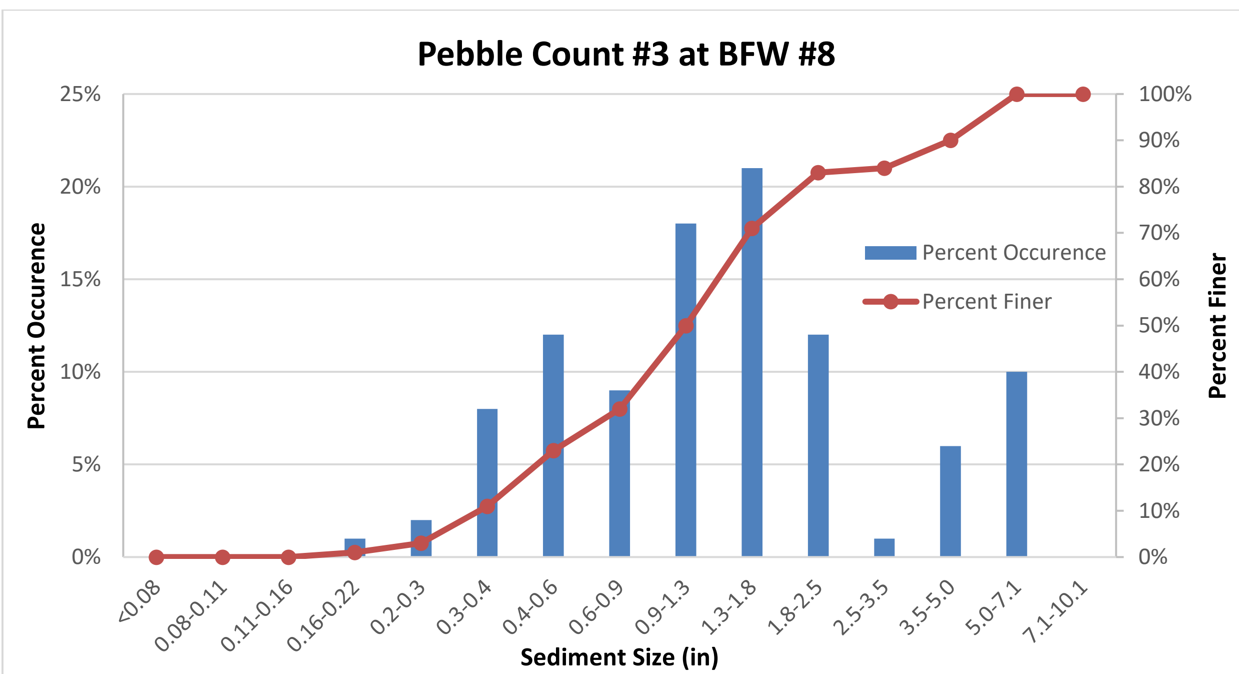


Figure 54: Pebble Count #3

Figure 55: South Tributary Reference Reach Pebble Count #3

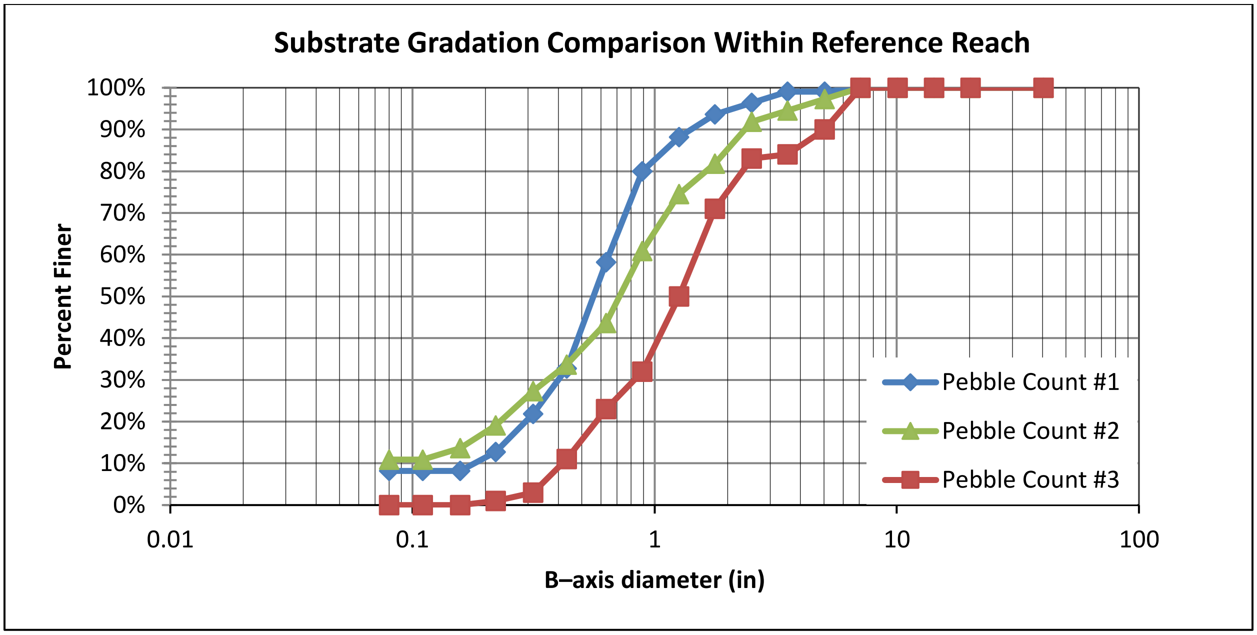


Figure 56: South Tributary Reference Reach Pebble Count Gradation

Table 11: South Tributary Pebble Count Gradation Within the Reference Reach

	Pebble Count #1 (inches)	Pebble Count #2 (inches)	Pebble Count #3 (inches)	Average Diameter (inches)
D_{min}	0.1	0.1	0.2	0.1
D_{16}	0.3	0.2	0.5	0.3
D_{50}	0.6	0.7	1.3	0.8
D_{84}	1.1	1.9	3.5	2.2
D_{max}	7.1	7.1	7.1	7.1

Figure 57: South Tributary Reference Reach Large Boulder

Figure 58: South Tributary Reference Reach Large Boulder

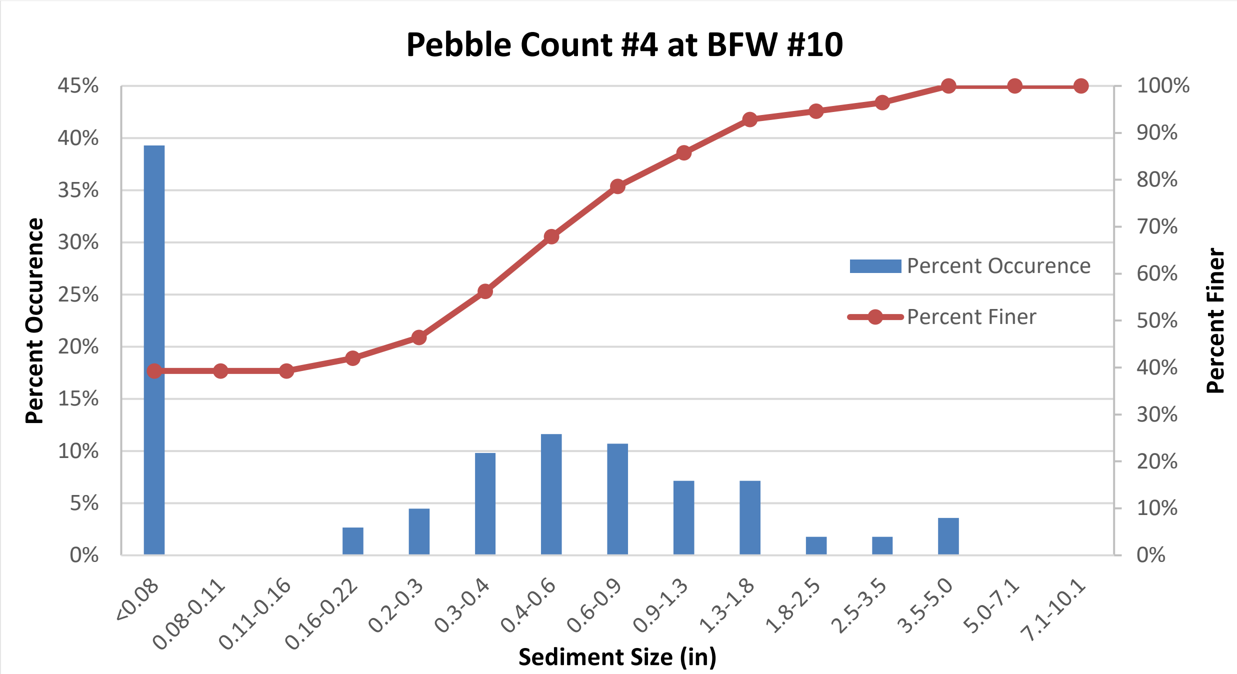


Figure 59: Pebble Count #4

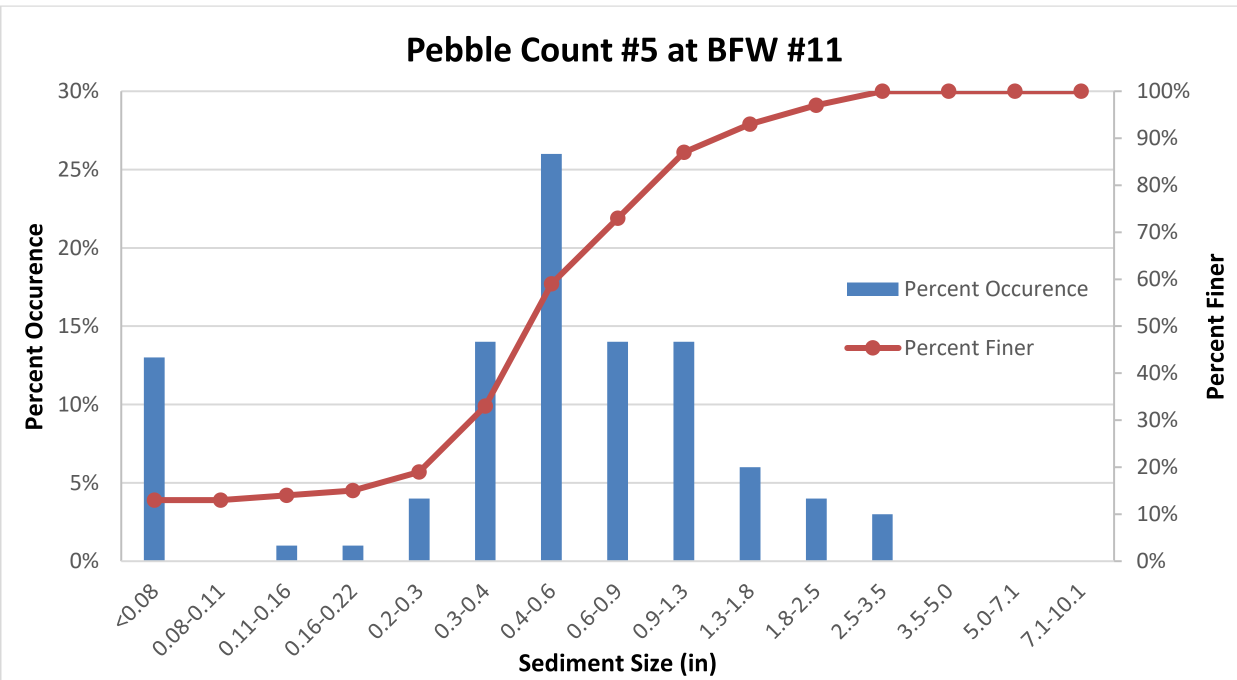


Figure 60: Pebble Count #5

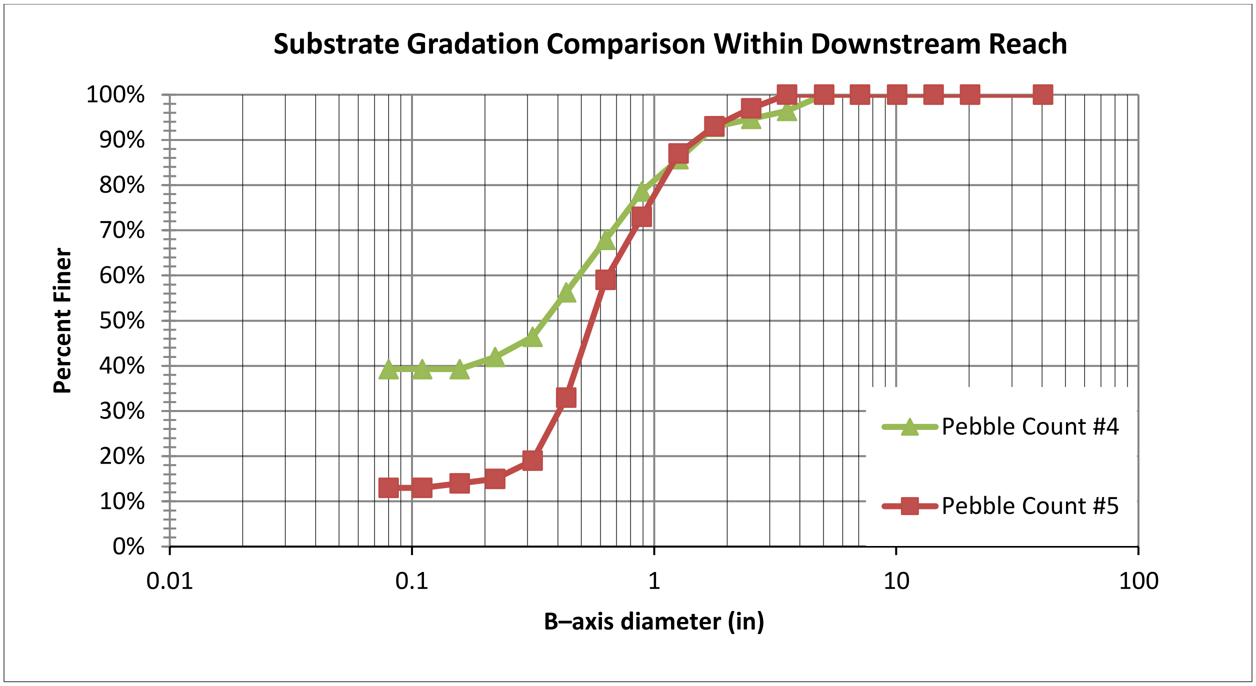


Figure 61: South Tributary Downstream Reach Pebble Count Gradation

Table 12: South Tributary Downstream Reach Pebble Count Data

	Pebble Count #4 (inches)	Pebble Count #5 (inches)	Average Diameter (inches)
D_{min}	0.1	0.1	0.1
D_{16}	0.1	0.2	0.2
D_{50}	0.4	0.6	0.5
D_{84}	1.2	1.2	1.2
D_{max}	5.0	3.5	4.3

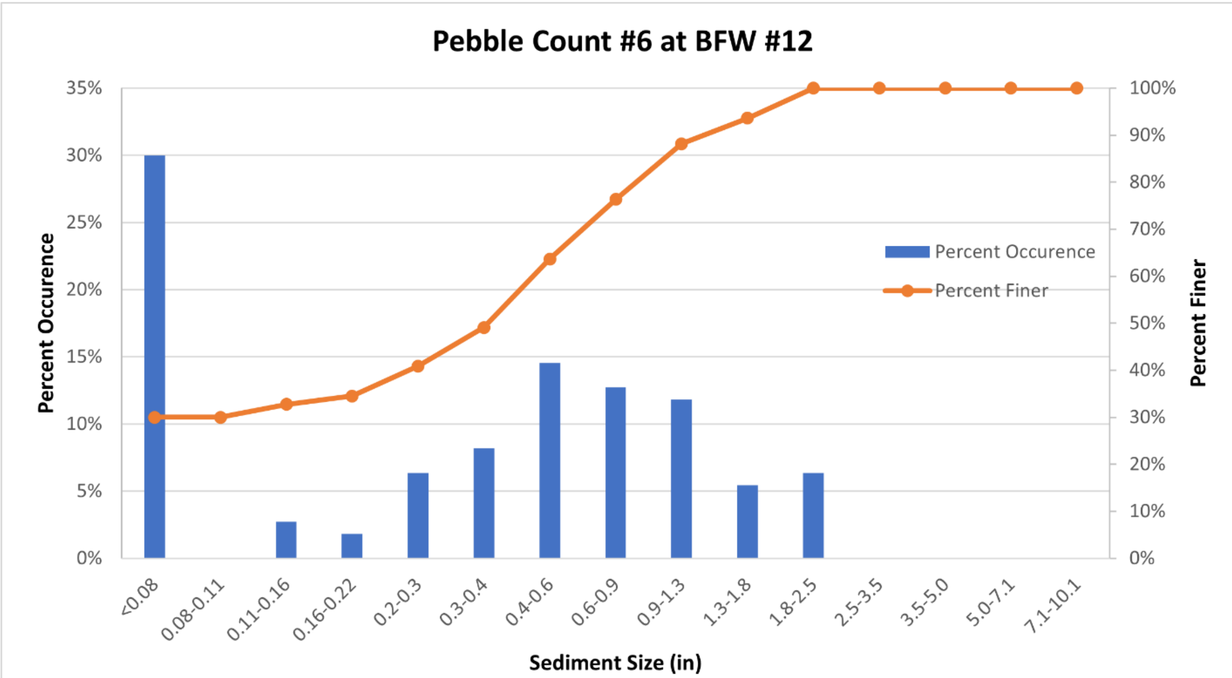


Figure 62: Pebble Count #6

Figure 63: South Tributary Downstream Design Reach Pebble Count #6

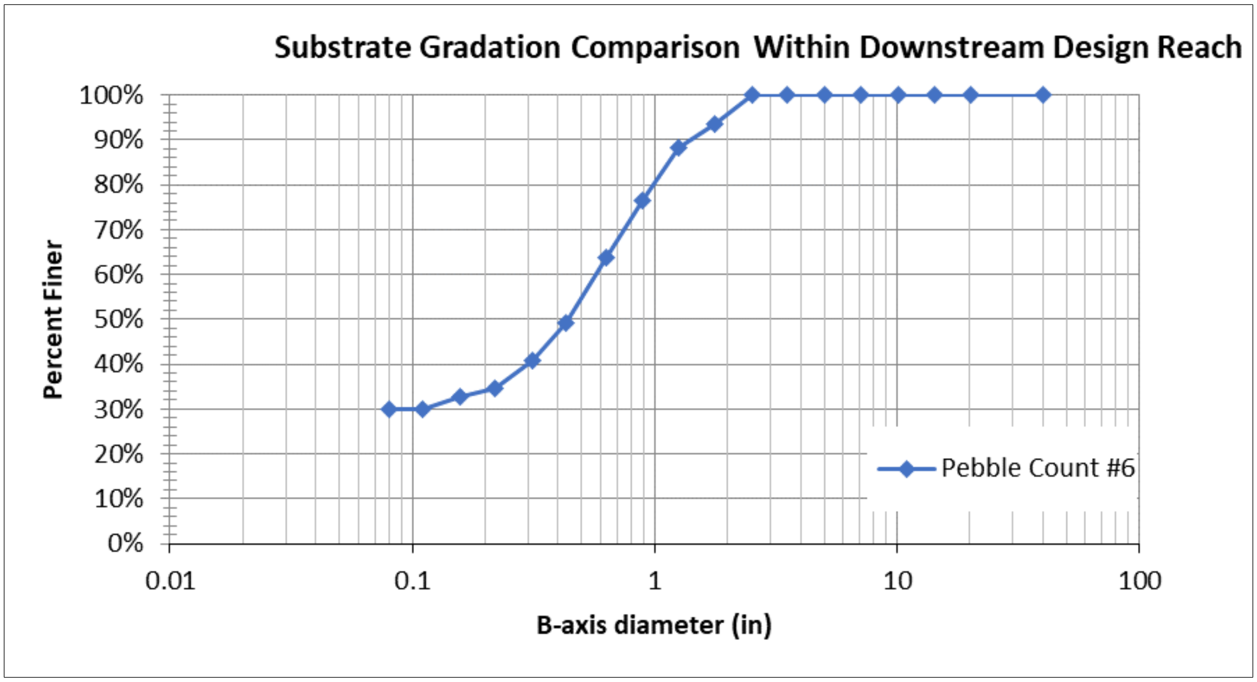


Figure 64: Substrate Gradation Within the Downstream Design Reach

Table 13: South Tributary
Downstream Design Reach Pebble Count Data

	Pebble Count #6 (inches)
D_{min}	0.1
D_{16}	0.1
D_{50}	0.4
D_{84}	1.1
D_{max}	2.5

2.8.4 Vertical Channel Stability

The longitudinal profile for the South Tributary is presented in Figure 65. The profile was created from the topographic survey collected for the project and the 2016 LiDAR (USGS 2020). Upstream of the I-5/Lake Samish Road interchange, the channel slope ranges from approximately 5.4 percent to 9.1 percent with a slope of 8.1 percent in the Reference Reach. At the I-5/Lake Samish Road interchange, where the stream is conveyed through an almost continuous alignment of culverts, the slope steepens and approaches 13 percent at Culvert 995235 (Figure 66). At the valley margin, the slope flattens to approximately 1.4 percent (between Culverts 995232 and 995245) and is 2.5 percent (below Culvert 995245) along the valley bottom (east of Barleen Road) and 0.1 percent near the stream's confluence with Friday Creek (Figure 65).

The potential curve of equilibrium shown in Figure 65 was visually estimated along the profile slope and represents the potential channel aggradation and degradation on a longer, geological timescale.

Areas of incision were observed throughout the Upstream Reference Reach upstream of the I-5/Lake Samish Road interchange (Figure 67). This channel incision does not appear to be the result of widespread head cutting, but rather the result of the channel downcutting along its steep alignment. Through the interchange, where the stream is conveyed through a series of culverts and open ditches, the stream grade is mostly controlled by the slopes of these crossings, which limit the overall vertical channel changes. With the existing culverts in place, the risk of vertical change is low. Deposition was noted downstream of Culverts 995233 and 995232, where the culvert outlets (particularly that of 995232) are almost totally submerged with accumulated sediment.

Downstream of the I-5/Lake Samish Road interchange, the stream is conveyed through a ditch adjacent to Barleen Road and through an agricultural ditch prior to flowing into Friday Creek. The ditches are artificial water courses and have an incised, trapezoidal channel geometry. This lower reach appears to be mostly a depositional area with its low channel slope and location at the base of the steeper grade through the I-5/Lake Samish Road interchange. Maintenance has likely been required over the years to maintain conveyance through the ditch.

Aggradation

WSDOT has removed sediment from the outlet of Culvert 995232 and documented removal of 15 cubic yards in 2018 (Case, personal communication, April 21, 2021). Based on the available photos of the culvert, the depth of sediment was approximately equal to culvert diameter (24 inches) (Figure 21). Based on this, almost 2 feet of aggradation occurred in the channel at the outlet of Culvert 995232. This culvert outlet is located where the channel slope changes from the steeper reach under I-5 to the flatter slopes near the valley bottom. Sediment has accumulated at the Culvert 995232 outlet to approximately 2 feet in depth during the site visits in January 2021 (Figure 20). The potential for aggradation at the slope transition/break at Culvert 995232 will continue under existing conditions. Aggradation of 2 to 4 feet in the short-term (10 years) is possible at this location. This is based on the WSDOT's photo record and maintenance record of the aggradation at the Culvert 995232.

Sediment is supplied from the upstream areas in the watershed from both alluvial and colluvial processes. The stream transports this sediment out of the steeper, upper watershed areas to the project area, where this sediment is further transported downstream through the culverts and deposited in the lower-gradient areas of the interchange and in the downstream valley. The potential for aggradation with the proposed project is discussed in Section 8.2.

Degradation

Upstream of I-5 (Upstream Reach), the channel is incised and is likely to continue to incise along its alignment. The rate of incision appears to be low due to the step-pool morphology that prevents further downcutting, acts as local grade controls, and retains sediment. Channel degradation through Project Reach at I-5 is limited by the almost continuous alignment of culverts which limit vertical channel bed changes along the steep slope at the I-5 crossing (approximately 13 percent). Downstream of I-5, the potential for degradation is low due to the low slopes as the stream enters the valley floor and floodplain of Friday Creek.

Grade Controls

The locations of the six barriers (Culverts 995236 through 995232, and 995245) within the I-5/Lake Samish Road interchange, as well as the one private culvert (931904) located upstream of the project area at the logging road crossing, represent the anthropogenic controls on grade in the watershed.

Bedrock grade controls were not observed in the channel. However, local, small-scale grade control is provided by the step-pool morphology found within the Upstream Reach. These step features are locally formed by boulders and in-channel woody material and locally influence the channel grade. Downstream of I-5, grade control features are generally lacking throughout the channel. One grade control feature (humanmade) was observed immediately downstream of the private culvert at Barleen Road (931905). Natural grade control features were not observed downstream of I-5.

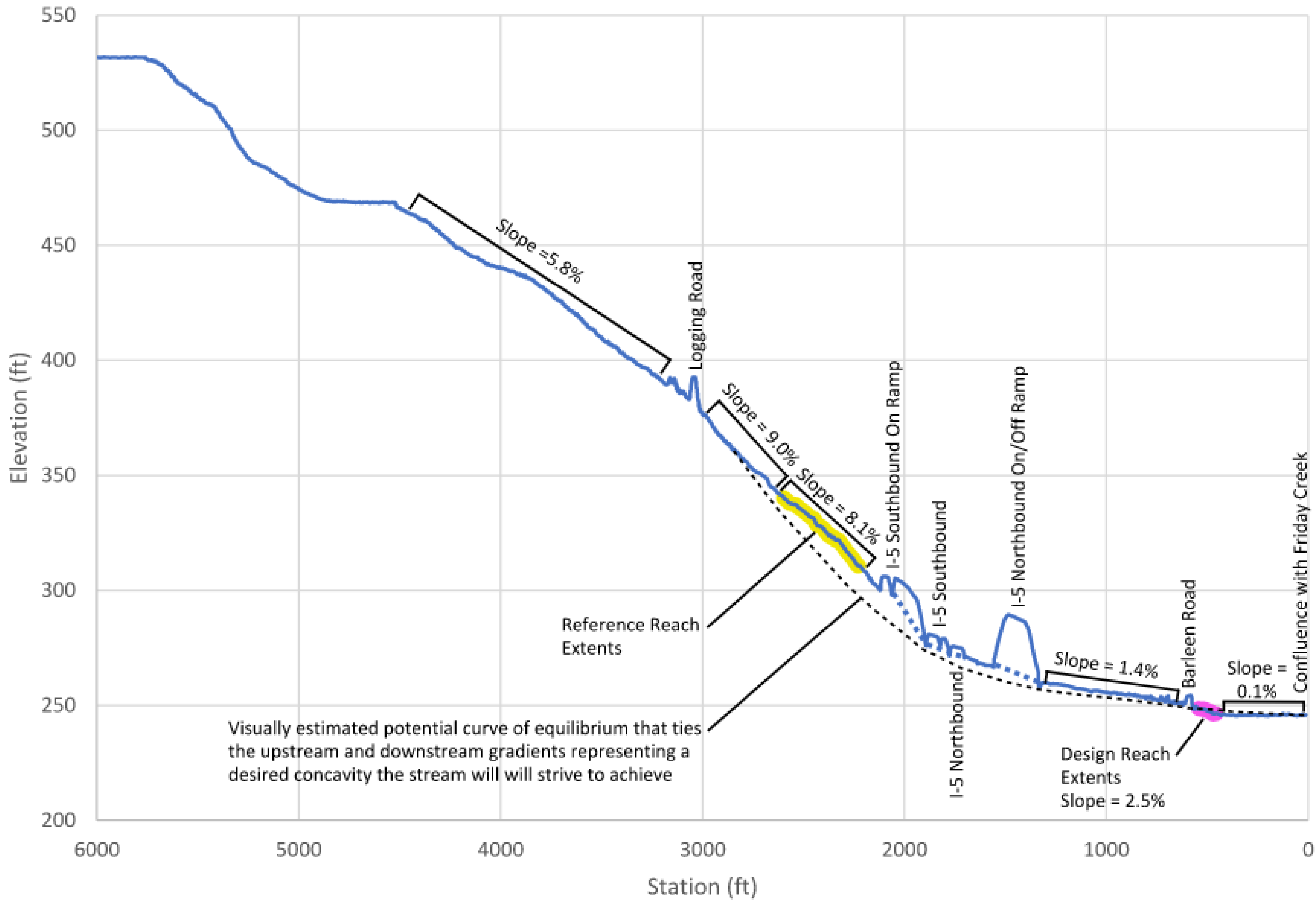


Figure 65: South Tributary Watershed Scale Longitudinal Profile

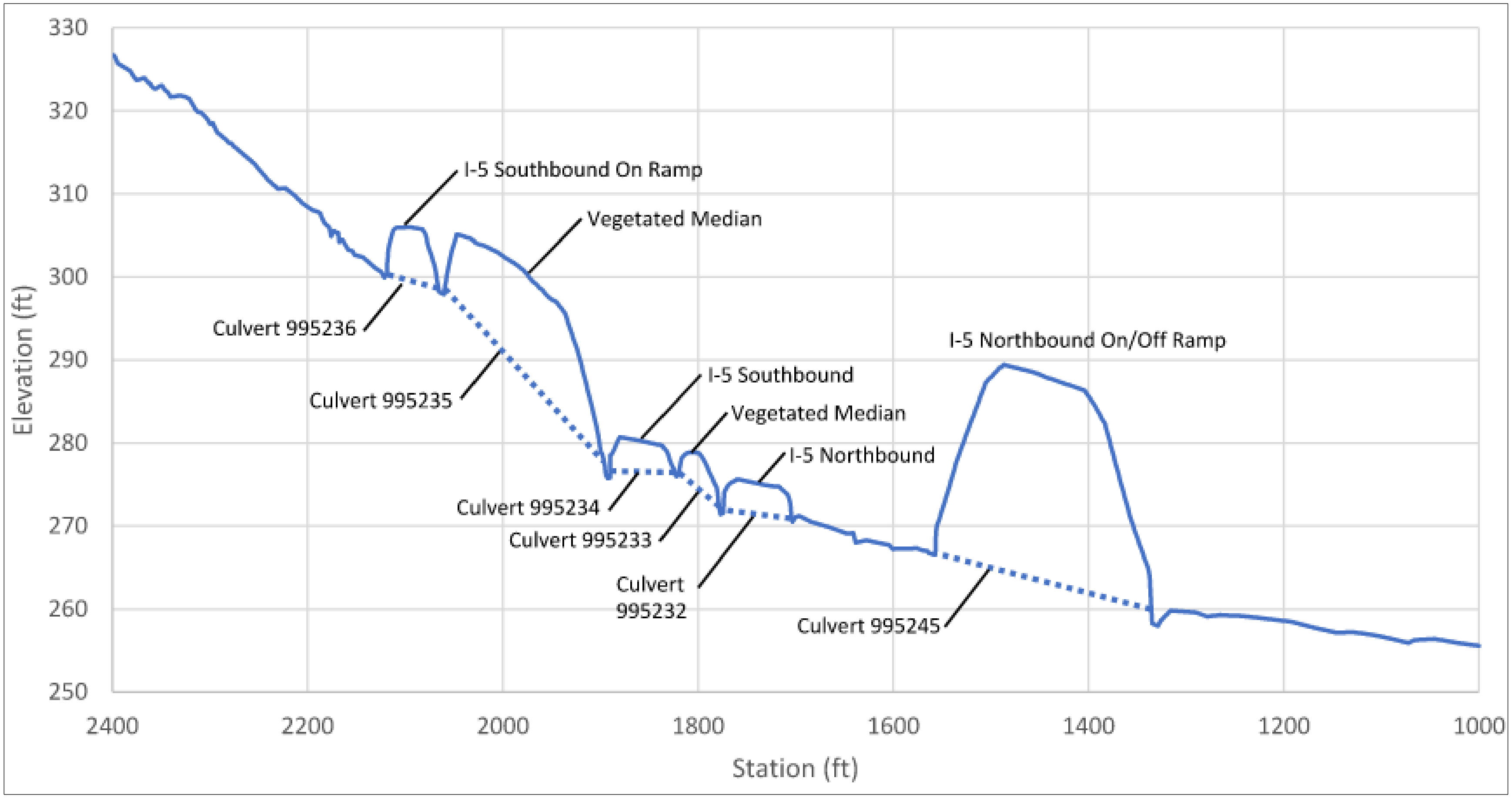


Figure 66: Stream Profile through I-5/Lake Samish Interchange (Project Reach)

Figure 67: Channel Incision in the Reference Reach

2.8.5 Channel Migration

Upstream Reference Reach

In the Upstream Reference Reach, the stream channel flows within a moderately steep, confined valley with a narrow floodplain along its margins. The channel alignment appears stable with limited migration. The stream flows within its well-established channel along its alignment and has a low sinuosity. Where present, the riparian and bank vegetation limit lateral channel movement and migration. There is evidence of erosion along the bank toes, but it does not appear to influence widespread channel migration or movement. Banks consist of both cohesive (glacial till) and non-cohesive sediments (alluvium and colluvium). In the Upstream Reference Reach, there is the risk for channel migration but it is limited to the factors listed above and by width of the steep forested ravine. Floodplain flow paths are not observed during the site investigation.

Project Reach

Through the I-5/Lake Samish Road interchange, the stream flows through a series of six culverts with limited daylighting between each culvert. The existing migration potential through the piped segments of this reach is low due to this mostly continuous piped (via culverts) and channelized conveyance through the steep interchange. However, where the stream grade flattens downstream of Culvert 995233 and Culvert 995232 there is a risk for channel migration where the stream is daylighted between the culverts and sediment deposition occurs (Figure 17 through Figure 21).

Downstream Reach (including Downstream Design Reach)

Downstream of I-5, the stream flows within a channelized ditch along its alignment adjacent to Barleen Road. The risk for channel migration along this reach is low. No floodplain flow paths were observed in the overbank flow areas. The fact that Barleen Road is located immediately adjacent to the stream's left bank (throughout most of this reach) limits the stream's existing migration potential.

In the Downstream Design Reach, the migration potential increases as it flows through the 100-year floodplain of Friday Creek. The stream flows through a wooded area just downstream of Barleen Road (and private Culvert 931905), where there are no barriers to lateral channel movement. There is the risk for channel migration immediately downstream of Barleen Road. However, downstream of this reach, the stream is ditched and has a linear alignment along much of its extent to its confluence at Friday Creek.

2.8.6 Riparian Conditions, Large Wood, Other Habitat Features

Upstream Reference Reach

Within the Upstream Reference Reach, the forest canopy consists of Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), western redcedar, and red alder (*Alnus rubra*) trees approximately 40 to 45 years of age (Figure 68). The historical aerial photographic record shows the area was logged between 1976 and 1981. Understory vegetation within the stream riparian corridor along both banks consists mostly of salmonberry and red elderberry. Ground cover is dominated by western swordfern with other flora of foamflower (*Tiarella trifolita*) and wild strawberry (*Fragaria* ssp). Invasive blackberry was also present in the Reference Reach.

The riparian corridor along the stream is dominated by a stand of alder, with diameters breast height ranging from approximately 12 to 18 inches, and a thick understory of woody vegetation along both banks. The channel contains abundant small woody material from tree branches and stems and from the woody vegetation along the stream banks. In places, the smaller in-channel wood (less than 8 inches in diameter) is helping to form and maintain the forced step-pool morphology within the reach. The larger wood that has fallen along the stream corridor and spans the channel banks is not directly engaged with the stream flows. Beaver activity was not noted within the Reference Reach. Wood recruitment is dominated by windthrow and bank undercutting by lateral bank erosion at the toe. Overall, the woody material engaged in-stream flows has small diameters generally less than 8 inches.

The presence of large boulders was noted in the Reference Reach. These boulders appear to be immobile, and the largest measured approximately 27 inches. The boulders were located throughout the channel and were also associated with the step-pool morphology present throughout this reach.

Figure 68: Vegetation Conditions in the South Tributary Reference Reach

Project Reach

Through the I-5/Lake Samish Road interchange, where the stream is conveyed through a series of six culverts, vegetation consists mostly of grasses at the culvert inlet and outlet locations. No riparian corridor is present. Other vegetation in the area included western swordfern, invasive blackberry and a few conifer trees (Figure 69). There is limited to no canopy cover through the Project Reach. No in-channel wood or beaver activity was noted where the stream is daylighted between the culverts. There is no in-channel wood or large boulders providing any geomorphic function.

Figure 69: Vegetation Conditions at the I-5 Interchange

Downstream Reach (including Downstream Design Reach)

The Downstream Reach east of I-5 is highly modified, and the stream flows within a ditch for approximately 1,375 feet to its confluence at Friday Creek (Figure 70). Immediately downstream of the I-5 interchange, the stream flows adjacent to Barleen Road in a trapezoidal channel lacking a functioning riparian buffer and canopy. It then flows under Barleen Road through a private culvert (931905), which is identified by WDFW (2011b) as a zero percent passable concrete culvert, then flows in an open ditch for approximately 570 feet before flowing into Friday Creek.

Along Barleen Road, some canopy cover is provided by young conifer trees and some understory vegetation. This reach lacks functional in-stream wood. Limited beaver activity was noted along this reach; however, it appears to have no impact on the channel structure or morphology. Invasive blackberry and reed canarygrass are present along the stream banks. Elements contributing to in-channel morphology and structure, such as large boulders and functional in-channel wood, are lacking.

Figure 70: Vegetation Conditions in the South Tributary Downstream Reach Adjacent to Barleen Road

In the Downstream Design Reach, the stream has more cover and more riparian vegetation, including thick understory vegetation with abundant vine maple (Figure 71). Some small wood (2 to 3 inches in diameter) is present in the channel and is mostly associated with the vine maple trees. This wood provides minimal in-channel geomorphic structure and function. No obvious signs of beaver activity were noted in the reach. No large boulders were noted in the stream channel.

Figure 71: Vegetation Conditions in the South Tributary Downstream of Barleen Road (Design Reach)

3 Hydrology and Peak Flow Estimates

The South Tributary has a drainage basin upstream of I-5 that originates in the foothills west of I-5 (Figure 3). The South Tributary flows are conveyed below the I-5/Lake Samish Road interchange southbound on-ramp via Culvert 995236, which is the most upstream culvert in a series of six culverts at the project site (Figure 1).

The drainage basin boundary and size were determined by delineating the basin using 2017 North Puget Sound LiDAR data (USGS 2020) and the U.S. Geological Survey (USGS) StreamStats web application (USGS 2016) for comparison. The contributing basin area at the upstream Culvert 995236 at the highway crossing is 0.165 square mile (105.6 acres). The contributing basin area at the downstream Culvert 995245 is 0.173 square mile (110.7 acres). The basin boundaries were delineated for these two culvert inlets due to the increase in flow rates at the downstream culvert from the influence of the roadway impervious area, and an additional inflow from the south between the two culverts. The additional inflow is due to a culvert located approximately 300 feet south of Culvert 995236, at approximate MP 240.86 along I-5. The culvert drains runoff from approximately 20 acres of forested area into the median east of I-5 and upstream of the inlet of Culvert 995245.

The mean annual precipitation from 1981 to 2010 is 46.3 inches/year (PRISM Climate Group 2022). There are no streamflow gage records for the South Tributary that could be used to develop flow recurrence calculations. Peak flows for the hydraulic analysis of the South Tributary (Table 14) were determined using the USGS Regression Equation by the USGS (Mastin et al. 2016). The USGS Regression Equation is a methodology to determine peak flood flows for ungaged streams that is based on annual precipitation and basin size. This methodology also incorporates a regional skew coefficient that was developed specifically for the Pacific Northwest region using statistics for 649 unregulated stream gages in Washington, Idaho, Oregon, and western Montana. The South Tributary to Friday Creek falls within USGS Regression Region 3, which uses the following equation to estimate discharge at ungaged sites:

$$Q = a\,A^{b}\,P^{c}$$

Where:

Q = *Flood discharge in cubic feet per second (cfs) for indicated annual exceedance probability (AEP)*
A = *Drainage area*
P = *Mean annual precipitation*
a = *Constant (AEP)*
b and c = *Regional coefficients*

A summary of the peak flows is shown in Table 14. The equations were developed using stream gages throughout the region. These gage locations have drainage areas that range from 0.08 to 2,605 square miles and mean annual precipitation in the range of 33.29 to 168.0 inches. Because the basin area (0.173 square mile) and mean annual precipitation (46.3 inches) of the basin fall within these bounds, it is reasonable to use the regression equations to estimate recurrence interval flows at the crossing. The USGS Regression equation flows were used for comparison with the modeled peak flows described below.

Table 14: Peak Flows for the South Tributary at I-5/Lake Samish Road Interchange

Regression Mean Recurrence Interval (MRI)	Culvert 995236 Peak Flow (cfs)	Culvert 995245 Peak Flow (cfs)
2-year	4.8	5.0
5-year	7.6	8.0
10-year	9.6	10.0
25-year	12.0	12.6
50-year	13.9	14.5
100-year	15.9	16.5
2080 100-year	19.1	19.8
200-year	17.8	18.6
500-year	20.5	21.4

In order to account for the inflow from the roadway and interchange impervious area, the site was modeled using MGSFLOOD. The site is located in the 52 inches per year band of the Puget East rainfall time series in MGSFLOOD. Results at Culvert 995236 are based on 85.6 acres of forested area, and results at Culvert 995245 are based on 105.5 acres of forested area, 0.75 acre of grass area, and 4.25 acres of impervious area.

The MGSFLOOD peak flows were used as the inflow rates for the hydraulic modeling as described in Section 4.1.4. The calculated peak flows at the inlet to Culvert 995236 were used as the South Tributary inflow for the model. The drainage basin for the culvert near MP 240.86 was calculated separately to determine the inflow at that location for the hydraulic modeling. Flows were also modeled for the roadway impervious area separately in MGSFLOOD to determine the inflows downstream of the roadway interchange to Culvert 995245. The calculated peak flows are shown in Table 15.

Table 15: MGSFLOOD Peak Flows for South Tributary at I-5/Lake Samish Road Interchange

MGSFLOOD Mean Recurrence Interval	Culvert 995236 Peak Flow (cfs)	Inflow to Culvert near MP 240.86 Peak Flow (cfs)	Roadway Peak Flow (cfs)	Culvert 995245 Peak Flow (cfs)
2-year	3.1	0.7	2.2	5.1
5-year	5.6	1.3	3.0	9.0
10-year	7.8	1.8	3.4	12.3
25-year	11.7	2.7	4.2	18.5
50-year	13.6	3.1	5.4	20.4
100-year	14.6	3.4	6.3	22.2
2080 100-year	17.5	4.1	7.6	26.6
200-year	26.1	6.0	7.2	37.4
500-year	41.5	9.5	8.4	57.9

Note:

The MGSFLOOD modeled peak flow rates at Culvert 995245 are not a summation of the other peak flows due to the differences in runoff timing characteristics from the forested and impervious areas.

4 Hydraulic Analysis and Design

The hydraulic analysis of the existing and proposed I-5 South Tributary crossings at MP 240.92 and MP 240.95 was performed using the U.S. Bureau of Reclamation's Sedimentation and River Hydraulics – Two-Dimensional Model (SRH-2D) Version 3.2.4 computer program (USBR 2017), a two-dimensional hydraulic and sediment transport numerical model. Pre-and post-processing for this model was completed using Surface-water Modeling System (SMS) Version 13.1.12 (Aquaveo 2021).

Three scenarios were analyzed for determining stream characteristics for the South Tributary with the SRH-2D models: 1) existing conditions with the six existing culverts (995236, 995235, 995234, 995233, 995232, and 995245); 2) natural conditions, where the culverts and I-5 are removed in order to simulate conditions prior to anthropogenic influences; and 3) future conditions with the proposed new channel alignments upstream and downstream of I-5 and the three fish-passage structures.

4.1 Model Development

4.1.1 Topographic and Bathymetric Data

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the Project Engineering Office (PEO), which were developed from topographic surveys performed by Otak in January 2021. The survey data were supplemented with 2016 DNR LiDAR data outside of the limits of the topographic survey data. All survey and LiDAR information are referenced against the North American Vertical Datum of 1988 (NAVD88). Several breaklines were added in the existing conditions model mesh to represent an area of the Barleen Road embankment beyond the limits of the topographic survey downstream where the LiDAR data did not accurately represent the road embankment elevation and width.

Proposed channel geometry was developed from the proposed grading surface created by Otak in September 2021 using Bentley InRoads and MicroStation.

4.1.2 Model Extent and Computational Mesh

The upstream and downstream extents were the same for the existing, natural, and proposed conditions models, and are shown in Figure 72 through Figure 80. The model domain begins approximately 600 feet upstream of Culvert 995236 and extends to about 300 feet downstream of Culvert 995245. The model extents were selected at these locations to enter inflow far enough upstream of Culvert 995236 and far enough downstream that the normal depth downstream boundary condition would not influence results at Culvert 995245.

The mesh size of the existing and natural conditions models was developed as approximately 1.5 feet wide by 1.5 feet long in the stream channel to provide a resolution to represent the stream channel bottom and banks, with mesh cells increasing in size outside of the stream channel. The proposed conditions model used the 1.5 feet by 1.5 feet mesh for the existing areas outside of the proposed grading but used an increased mesh density with cell sizes of 1 foot by 1 foot to represent the proposed channel and crossing structures.

The number of mesh elements is summarized for each model in Table 16. Quadrilateral elements were used to represent the stream channel and overbanks, while triangular elements were generally used to represent upland areas and roadways. The mesh covers a total area of approximately 17 acres.

Table 16: Summary of Mesh Elements Within Existing, Natural, and Proposed Conditions Models

Model	Quadrilateral	Triangular	Total
Existing Conditions	25,534	99,004	124,538
Natural Conditions	38,580	118,118	156,698
Proposed	46,879	131,173	178,052

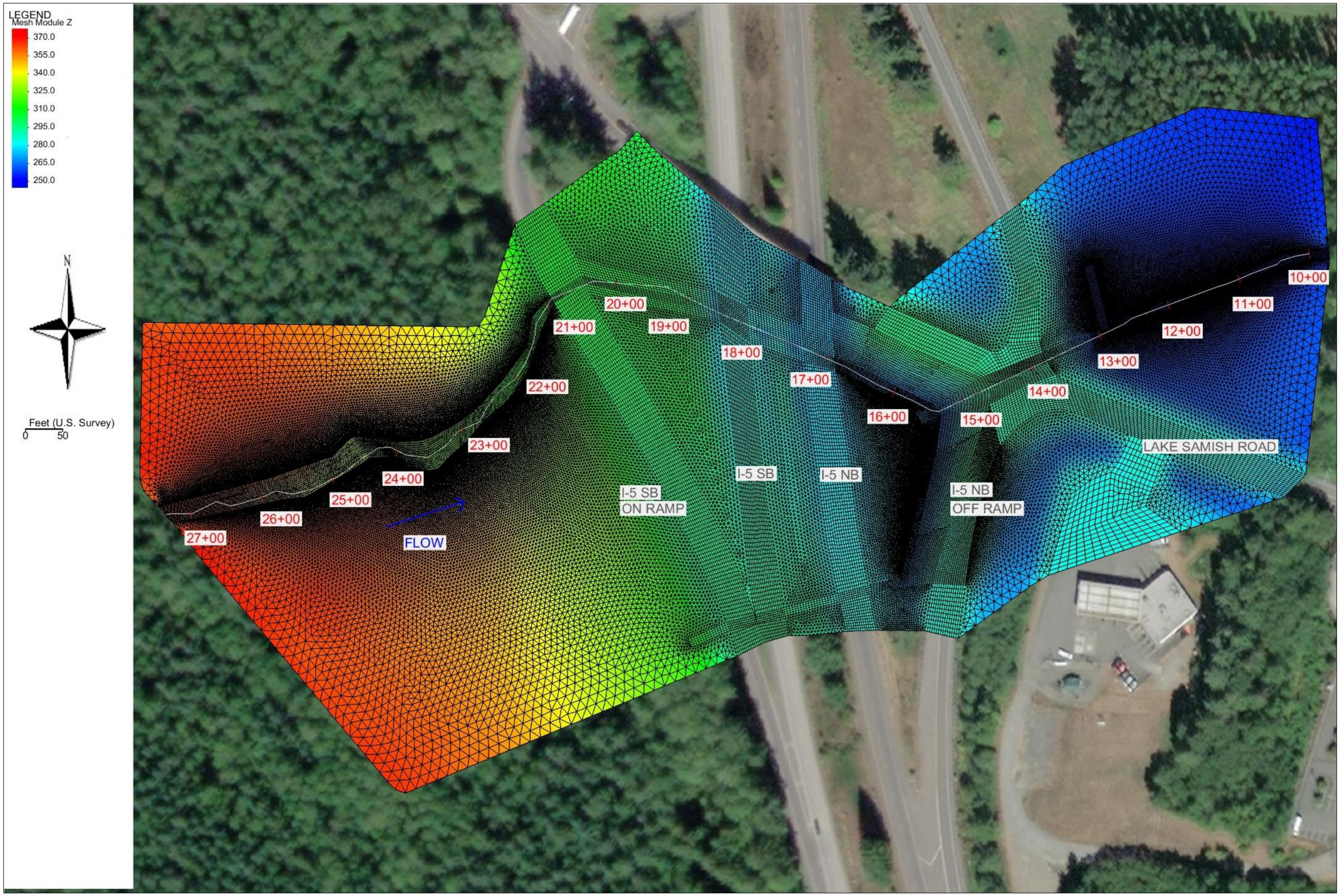


Figure 72: Existing Conditions Computational Mesh with Underlying Terrain (overall)

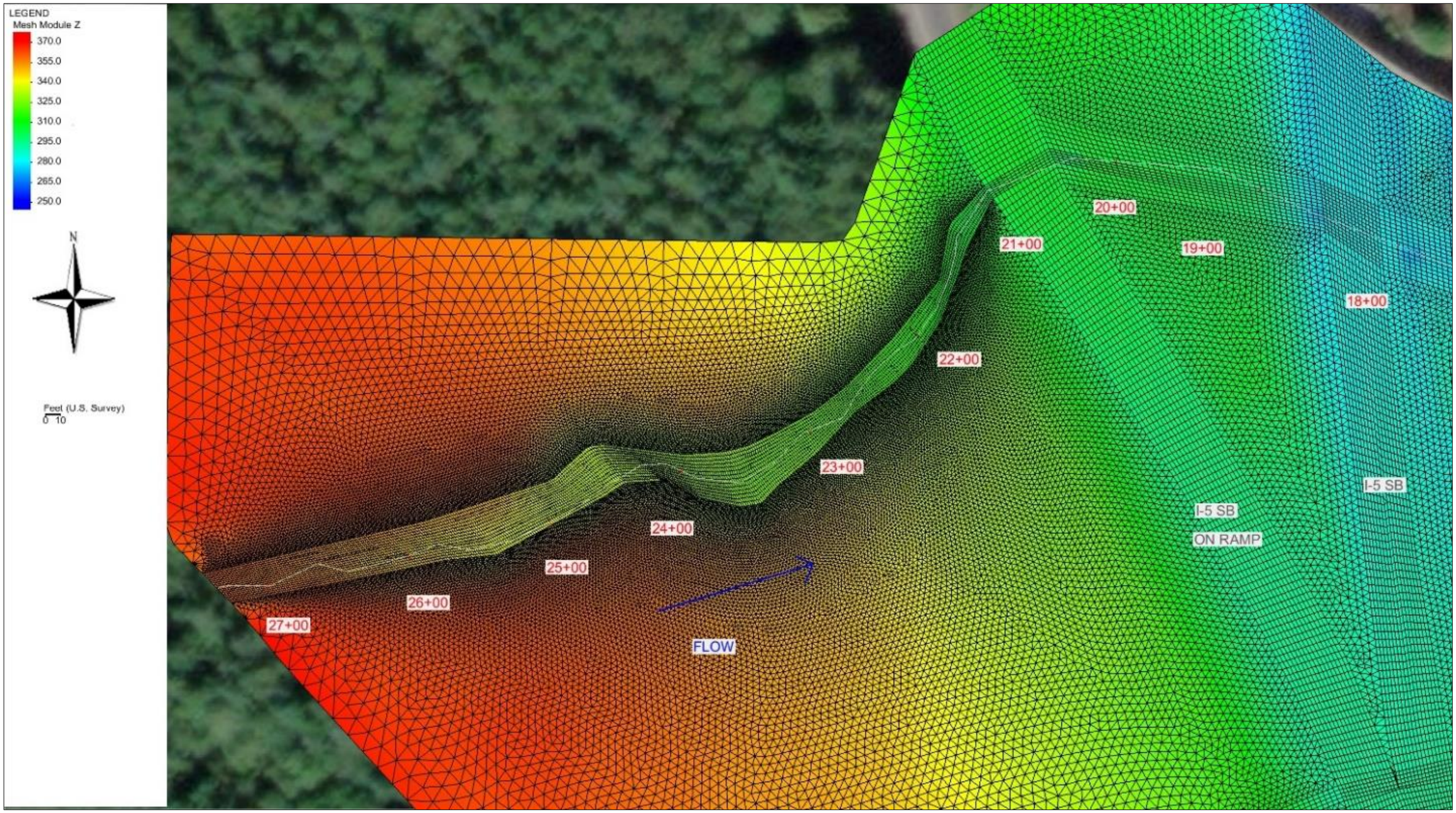


Figure 73: Existing Conditions Computational Mesh with Underlying Terrain (upstream)

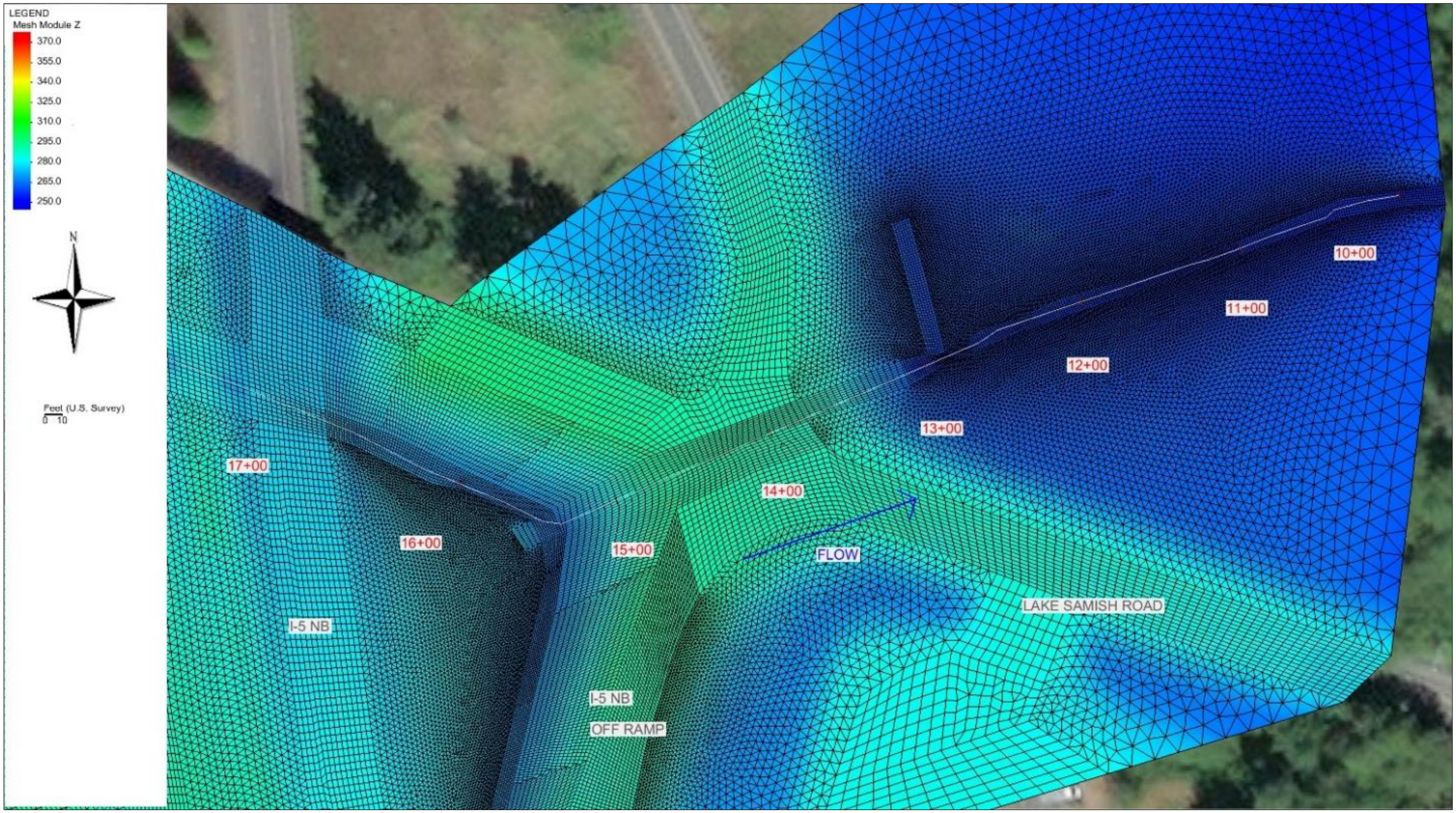


Figure 74: Existing Conditions Computational Mesh with Underlying Terrain (downstream)

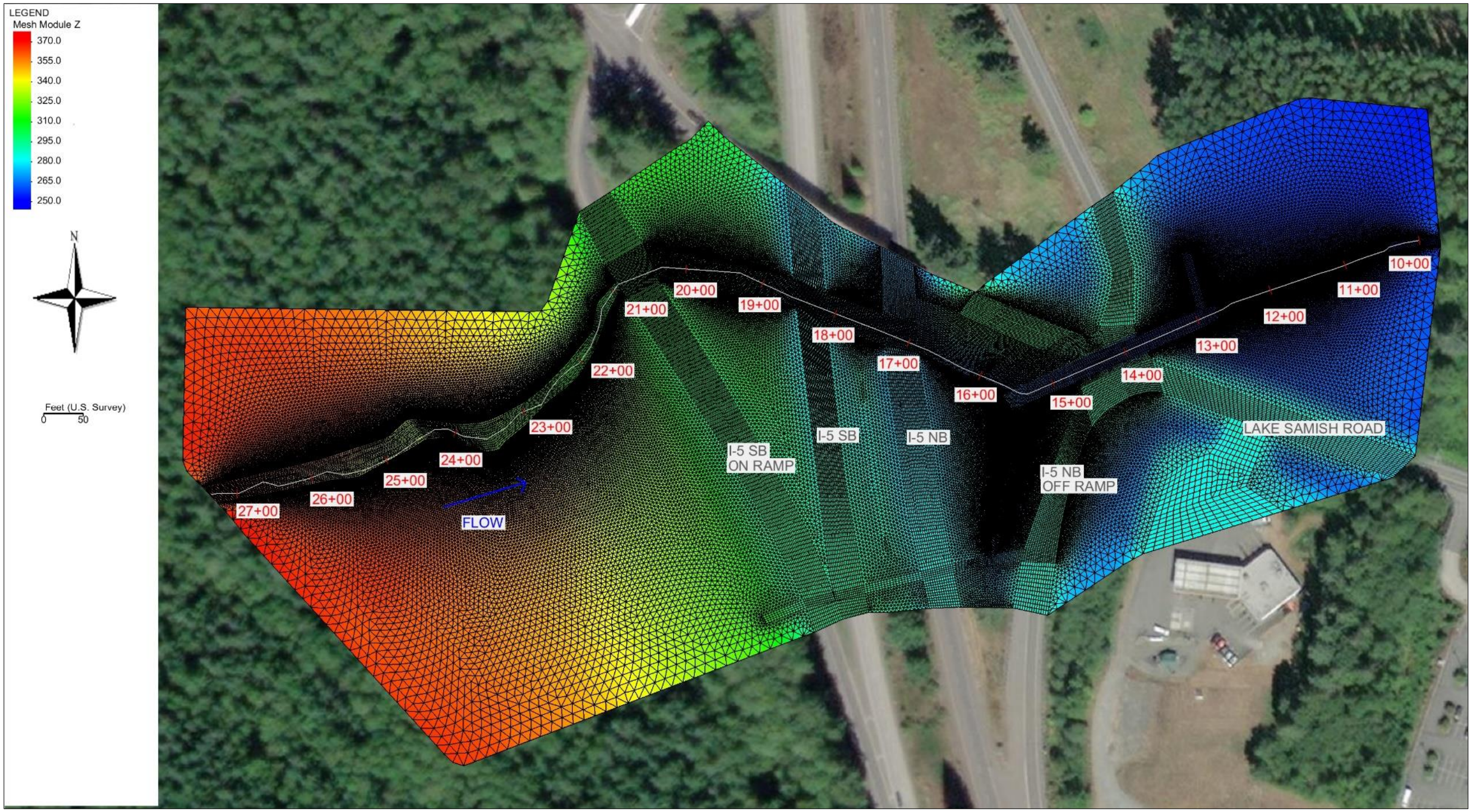


Figure 75**: Natural Conditions Computational Mesh with Underlying Terrain (overall)**

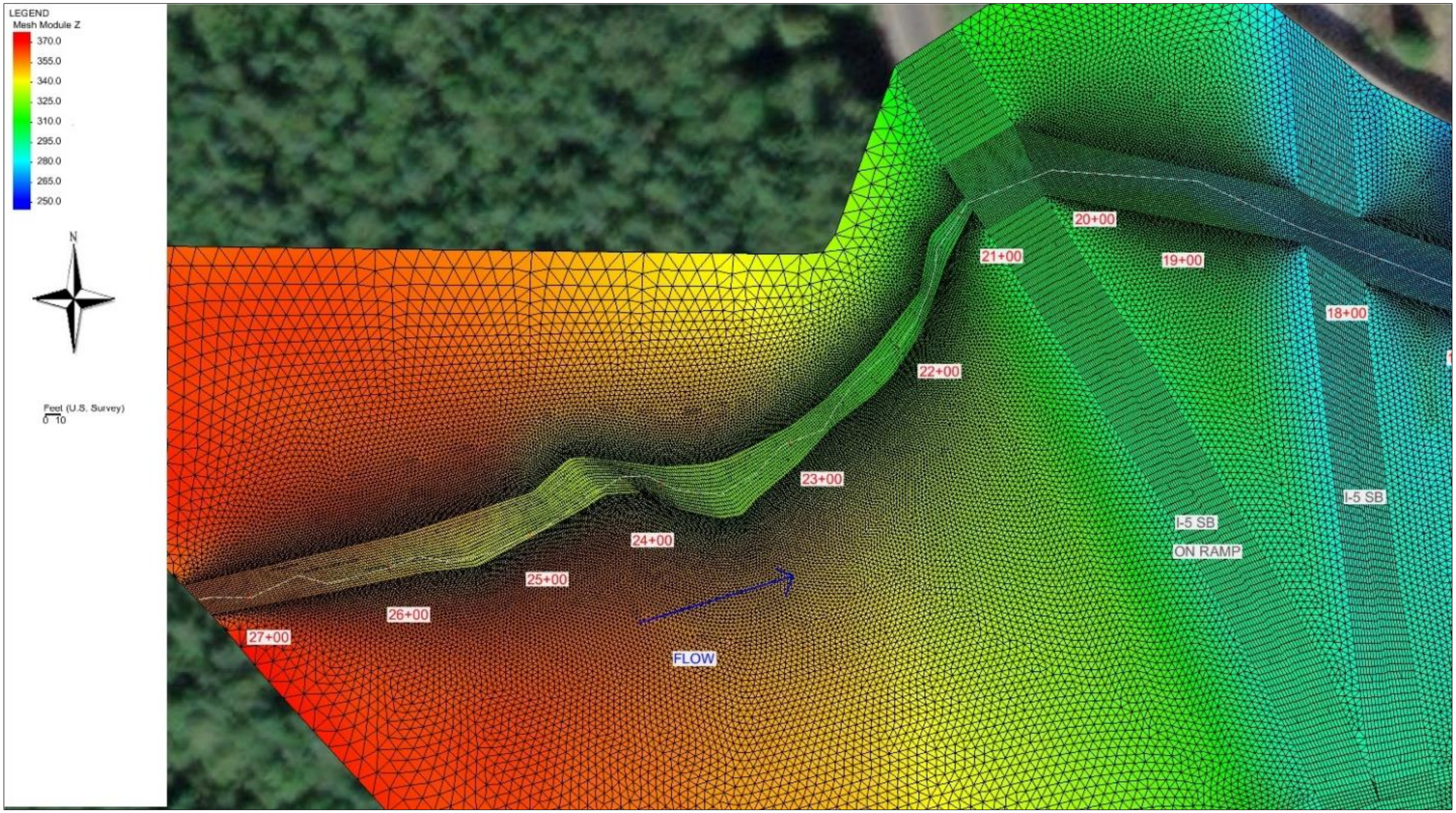


Figure 76: Natural Conditions Computational Mesh with Underlying Terrain (upstream)

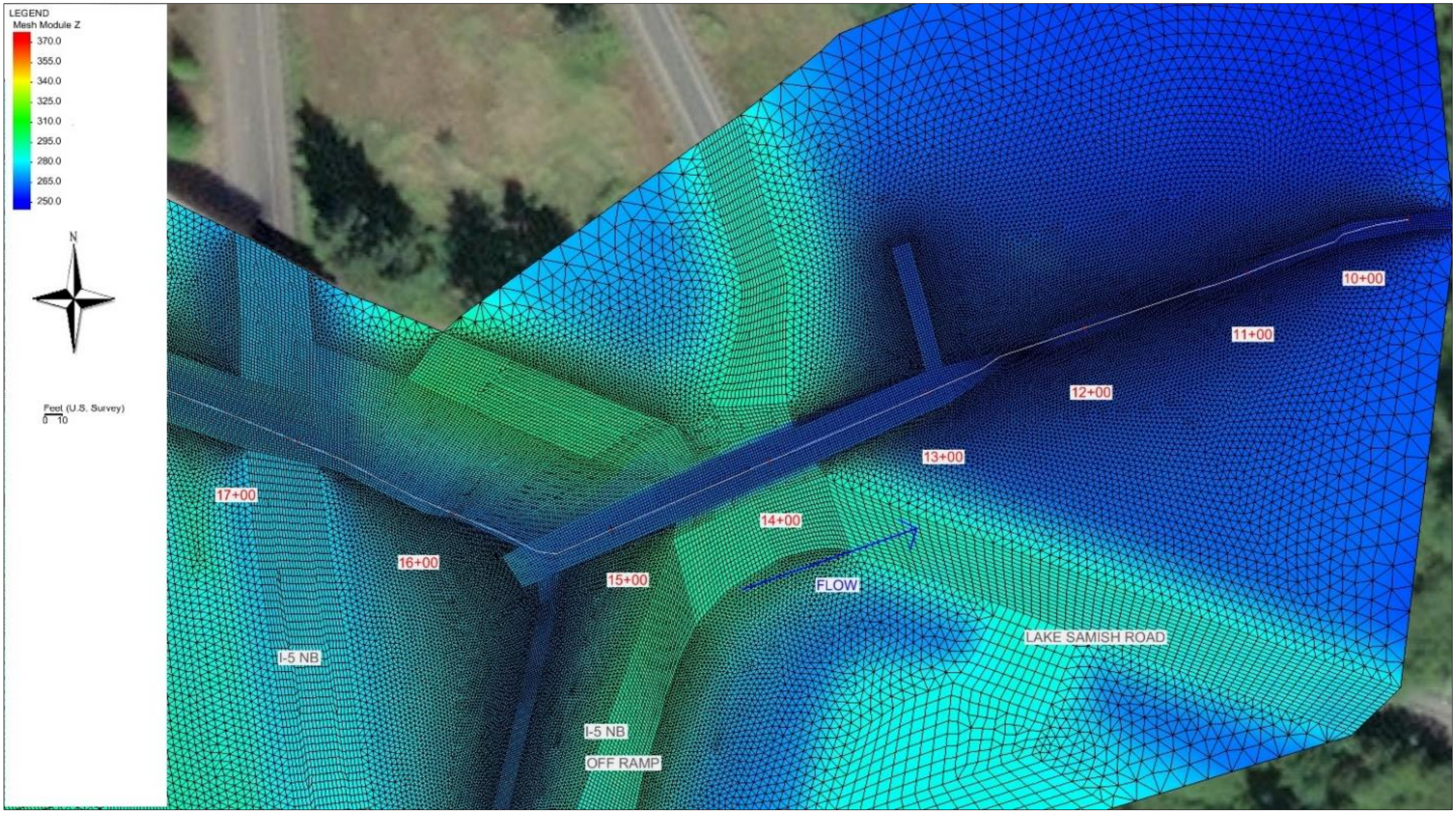


Figure 77: Natural Conditions Computational Mesh with Underlying Terrain (downstream)

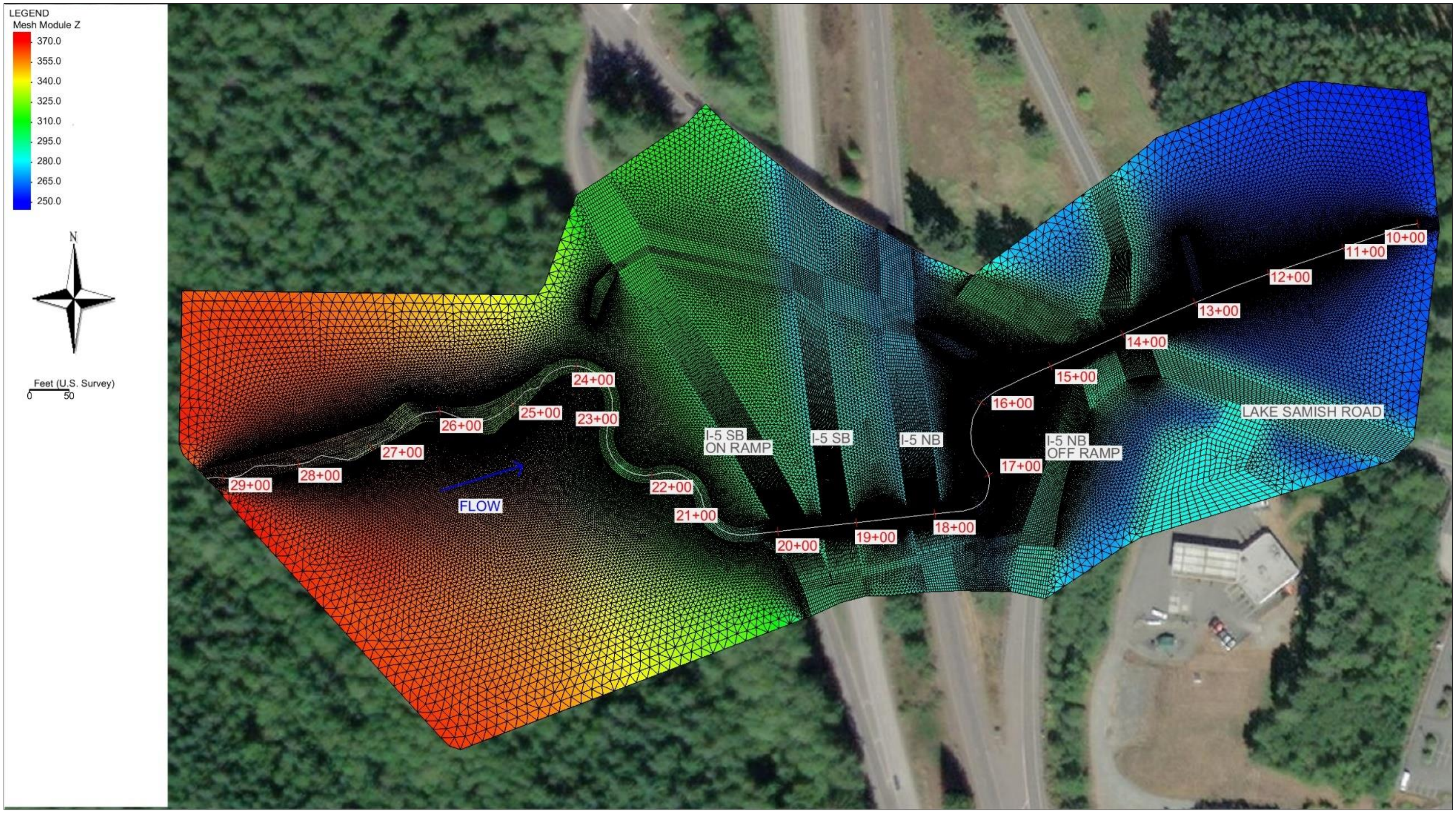


Figure 78: Proposed Conditions Computational Mesh with Underlying Terrain (overall)

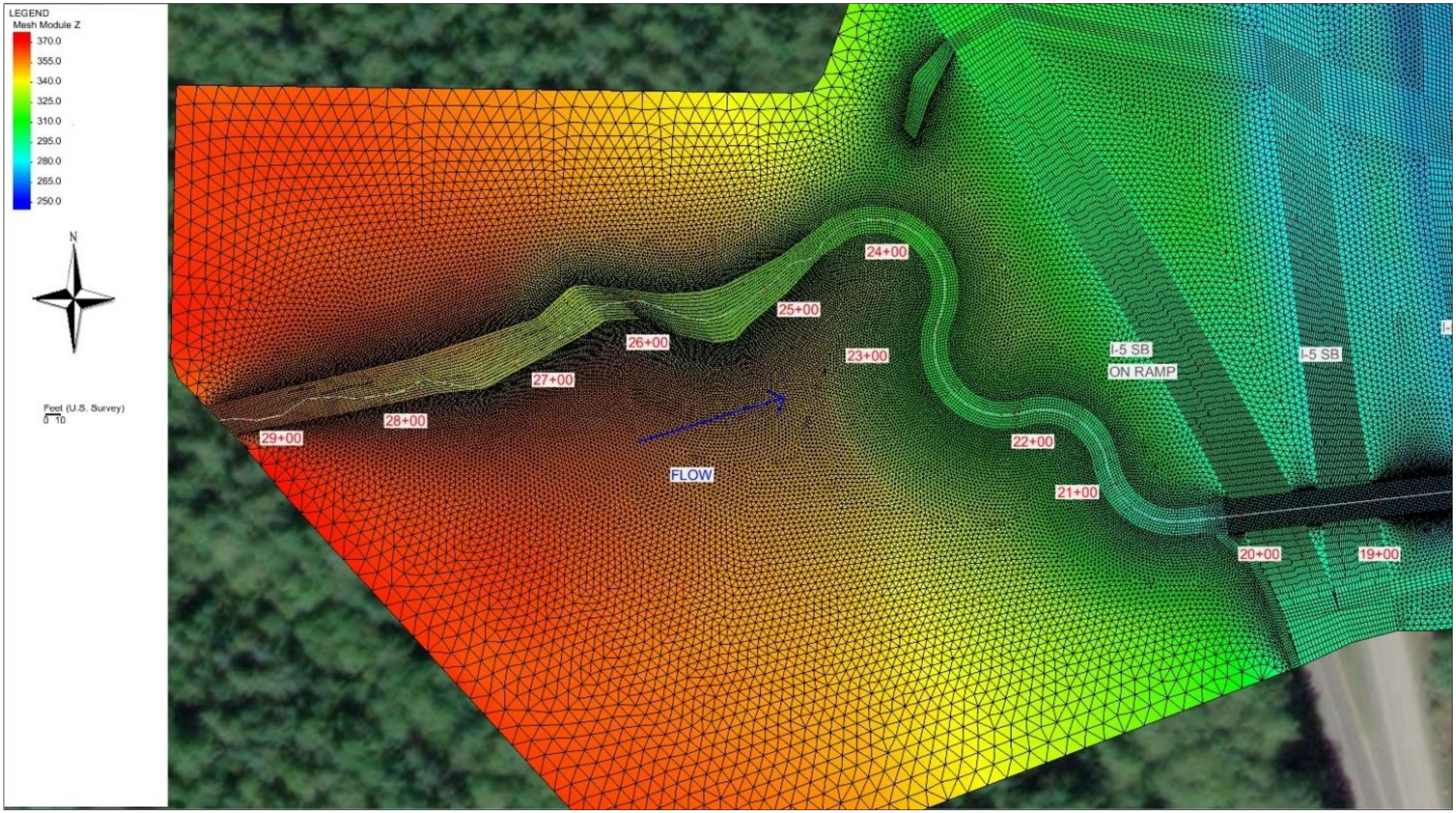


Figure 79: Proposed Conditions Computational Mesh with Underlying Terrain (upstream)

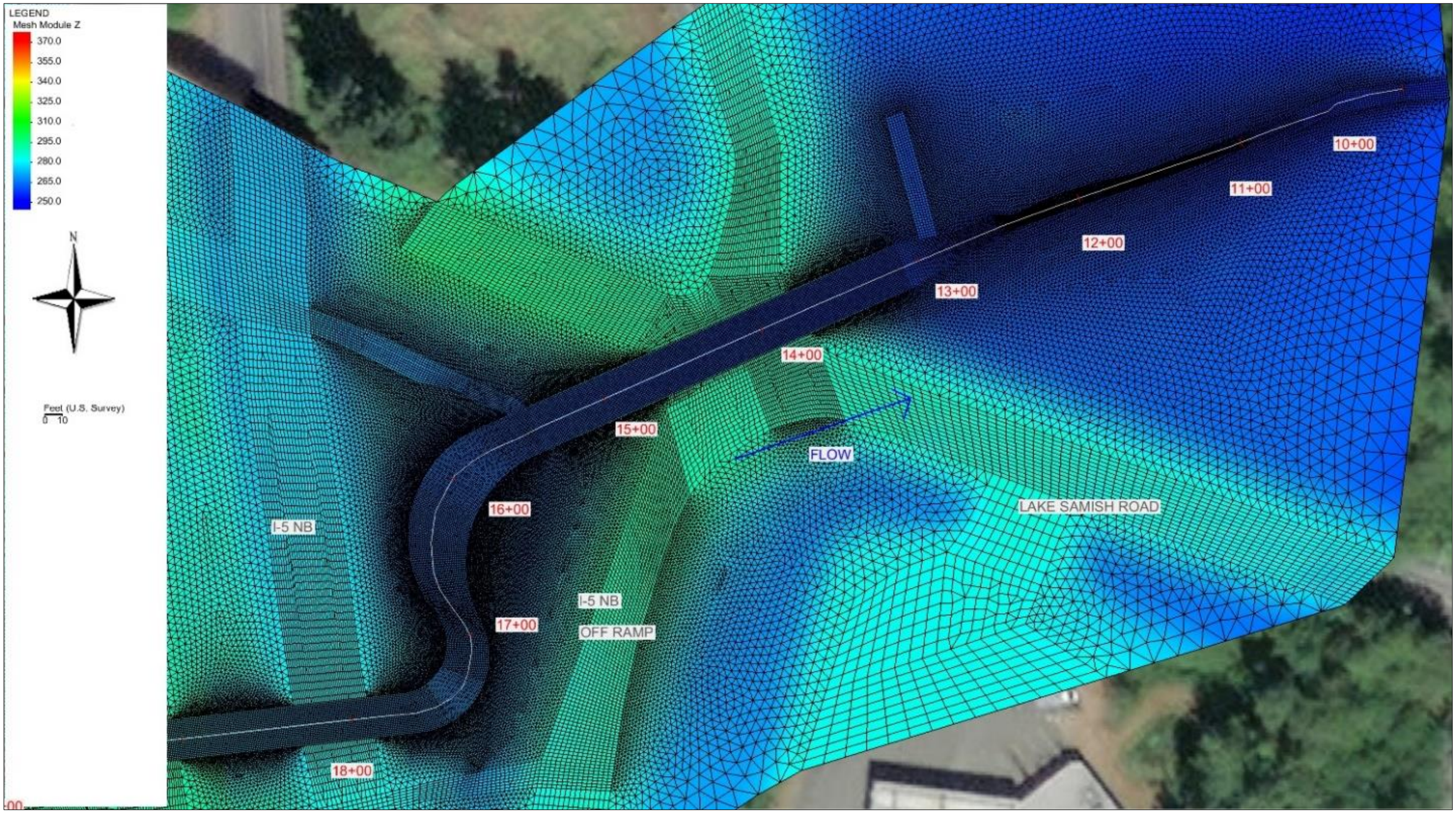


Figure 80: Proposed Conditions Computational Mesh with Underlying Terrain (downstream)

4.1.3 Materials/Roughness

The Manning' n roughness values for the existing, natural, and proposed conditions models were developed using methods including tabular guidance (WSDOT 2022a; Chow 1959; and others) based on field observations, photographic guidance (USDA 2014), and quantitative equations (Yochum et al. 2012). For existing conditions, quantitative methods for stream channel flow resistance in high-gradient streams (USDA 2018) were used for the upstream existing channel in combination with tabular guidance and photographs of similar stream reaches from the USGS. For the existing channels within the project area and downstream, the tabular guidance for roughness values was used and adjusted based on observed conditions for obstructions and vegetation. For the natural conditions model, the methods used for determining roughness values were the same as those used for the existing conditions model.

For the proposed conditions model, the roughness values were developed for the proposed stream channel and within proposed structures using tabular guidance and adjusting for proposed obstructions such as large wood and boulders, as well as vegetation. Outside of the proposed stream channel and structures, the proposed conditions model used the same roughness values as the existing conditions model. A summary of the roughness values used in the models is provided in the following sections and in Table 17 through Table 19.

Existing Conditions

Upstream Channel

A composite Manning's n value of 0.110 was used for the Upstream Reach of the South Tributary to the Friday Creek channel (Table 17). Methods from the USFS (Yochum et al. 2012) calculated a roughness value of 0.179. Photographic guidance from the USGS for a similar step-pool system (Fool Creek, Colorado, FC-2; USDA 2014) indicated a roughness value of 0.130 at bankfull flow. A tabular method using a base Manning's n value for mountain streams of 0.050 (WSDOT *Hydraulics Manual*, Figure 4A-2) used an adjustment factor of 0.005 for obstructions due to large wood and boulders and a factor of 0.030 for vegetation to estimate 0.085 for the Upstream Reach. These three methods were averaged to provide a Manning's n roughness value of 0.111 for the Upstream Reach. These calculations are shown in Appendix G.

Median Channel and Downstream Channel

A Manning's n value of 0.035 was used for the existing conditions stream channel in the median of I-5 and downstream of Culvert 995245 (Table 17). The value was assigned using tabular value for a relatively uniform earthen channel section with little or no brush (WSDOT *Hydraulics Manual* Figure 4A-2). No adjustments were applied to the base value due to the lack of consistent obstructions or vegetation within the flow path in these reaches.

Floodplain – Light Brush and Medium Brush

A roughness value of 0.080 was used for floodplain areas with light brush, and a value of 0.160 was used for floodplain areas with dense brush. These values were assigned using the range of tabular values from the WSDOT *Hydraulics Manual* (2022a) Figure 4A-2 and estimating these roughness values based on observed field conditions for the sparsely vegetated median areas (light brush), and the heavily vegetated forested areas (medium brush) (Table 17).

Road

Impervious areas for roadways were assigned a Manning's n roughness value of 0.016 using guidance for paved areas in the SRH-2D manual (FHWA 2019, after Chow 1959).

The spatial distribution of the roughness values in the existing conditions model is shown in Figure 81.

Natural Conditions

The natural conditions model used the same Manning's n values as the existing conditions model, except for the natural stream channel modeled from Culvert 995236 to Culvert 995245. For the natural conditions channel on the steep slope (from the inlet to Culvert 995236 to the inlet of Culvert 995234), the same Manning's n roughness as the Upstream Reach (0.110) was used. For the natural conditions channel over the lower slope (Culvert 995234 through Culvert 995245), the downstream Manning's n value of 0.035 was used. The spatial distribution of the roughness values in the natural conditions model is shown in Figure 82.

Proposed Conditions

The proposed conditions model used the same roughness values as the existing conditions model, except for the area of the proposed stream realignment and the proposed crossing structures. The proposed stream channel and crossing structures are summarized below. The spatial distribution of the roughness values in the proposed conditions model is shown in Figure 83.

Proposed Stream Channel with Large Wood

Within the upstream reaches with slopes from 6 percent to 8 percent, a base Manning's n value of 0.050 was assigned following values for mountain streams with gravel, cobbles, and a few boulders from WSDOT Figure 4A-2 (2022a). For the proposed stream channel from 3 to 6 percent slope, a base Manning's n value of 0.045 was assigned based on the lower end of the range for mountain streams with gravel and cobbles with a few boulders. For the proposed channel at a slope less than 3 percent, a base Manning's n value of 0.035 was assigned based on a fairly regular earthen channel section with light brush.

Adjustment value of 0.025 was added to account for large wood within the stream channel, following "appreciable" obstructions occupying 15 percent to 50 percent of the cross-sectional areas from the USGS (Arcement and Schneider 1989). An adjustment value of 0.010 was added for small vegetation, such as tree and shrub seedlings—from the same table—to account for small plantings within the overbanks of the stream channel post-construction. As this roughness value is applied only to the proposed bankfull channel, a 0.010 adjustment value was appropriate as there is limited anticipated vegetation within the active bankfull channel due to the anticipated streamflow. The resulting proposed channel roughness values with large wood and small vegetation are, therefore, 0.085 for slopes over 6 percent, 0.080 for slopes from 3 to 6 percent, and 0.075 for slopes under 3 percent, respectively.

Proposed Crossing Structures

Similar base values were assigned for the streambed material within the proposed crossing structure as the proposed stream channel. A base value of 0.050 was assigned for the structure on the 6 to 7 percent slope, 0.040 for the structure on the 4 percent slope, and 0.035 was assigned for the structure on the 1.7 percent slope to account for a gravel and cobble bottom. An adjustment value of 0.015 was added for minor obstructions (occupying less than 15 percent of the cross-section area) from the USGS (Arcement and Schneider 1989) to account for the effect of meander bars and boulders on the relatively shallow depth of flow through form roughness in the 2D model. The sinuosity of the channel forced by the proposed meander bars and boulders in Structure 3 was included in the computational mesh to model the hydraulics through the proposed crossing. The resulting Manning’s n values for the crossing structure are, therefore, 0.065 for the 6 percent slope, 0.060 for the 4 percent slope, and 0.045 for the 1.7 percent slope.

Table 17: Manning's n Hydraulic Roughness Coefficient Values Used in the Existing Conditions SRH-2D Model

Land Cover Type Existing Conditions	Manning's n	Reference
Existing Upstream Channel	0.11	Stream Channel Flow Resistance Coefficient Computation Tool (Version 1.1,2-2018)
Existing Median Channel	0.035	WSDOT Figure 4A-2 (2022a)
Existing Downstream Channel	0.035	WSDOT Figure 4A-2 (2022a)
Floodplain — Light Brush and Trees, in Summer	0.08	WSDOT Figure 4A-2 (2022a)
Floodplain — Medium to dense Brush and Trees, in Summer	0.16	WSDOT Figure 4A-2 (2022a)
Asphalt Pavement	0.016	SRH-2D Manual (FHWA 2019)
Existing Concrete Pipe Culvert	0.012	HEC-22 (Brown et al. 2009)
Existing Corrugated Metal Pipe	0.024	HEC-22 (Brown et al. 2009)

Table 18: Manning's n Hydraulic Roughness Coefficient Values Used in the Natural Conditions SRH-2D Model

Land Cover Type Natural Conditions	Manning's n	Reference
Natural Conditions Channel, Slopes of 3%–12%	0.11	Stream Channel Flow Resistance Coefficient Computation Tool (Version 1.1,2-2018)
Natural Conditions Channel, Slopes less than 3%	0.035	WSDOT Figure 4A-2 (2022a)
Existing Upstream Channel	0.11	Stream Channel Flow Resistance Coefficient Computation Tool (Version 1.1,2-2018)
Existing Downstream Channel	0.035	WSDOT Figure 4A-2 (2022a)
Floodplain — Light Brush and Trees, in Summer	0.08	WSDOT Figure 4A-2 (2022a)
Floodplain — Medium to dense Brush and Trees, in Summer	0.16	WSDOT Figure 4A-2 (2022a)

Table 19: Manning's n Hydraulic Roughness Coefficient Values Used in the Proposed Conditions SRH-2D Model

Land Cover Type Proposed Conditions	Manning's n	Reference
Existing Upstream Channel	0.110	Stream Channel Flow Resistance Coefficient Computation Tool (Version 1.1,2-2018)
Project Reach Channel, including large wood, Slope 6%–8.1%	0.085	WSDOT Figure 4A-2 (2022a), Arcement and Schneider (1989)
Crossing Structure, with step-pools, Slope of 6%–7%	0.065	WSDOT Figure 4A-2 (2022a), Arcement and Schneider (1989)
Project Reach Channel, including large wood, Slopes 3%–6%	0.080	WSDOT Figure 4A-2 (2022a), Arcement and Schneider (1989)
Crossing Structure, with step-pools, Slope of 3%–4%	0.060	WSDOT Figure 4A-2 (2022a), Arcement and Schneider (1989)
Project Reach Channel, including large wood, Slopes less than 3%	0.075	WSDOT Figure 4A-2 (2022a), Arcement and Schneider (1989)
Crossing Structure, with meander bars, Slope of 1.7%	0.045	WSDOT Figure 4A-2 (2022a), Arcement and Schneider (1989)
Floodplain — Light Brush and Trees, in Summer	0.080	WSDOT Figure 4A-2 (2022a)
Floodplain — Medium to dense Brush and Trees, in Summer	0.160	WSDOT Figure 4A-2 (2022a)
Asphalt Pavement	0.016	SRH-2D Manual (FHWA 2019)
Basin G Ditch	0.035	WSDOT Figure 4A-2 (2022a)
Existing Downstream Channel	0.035	WSDOT Figure 4A-2 (2022a)

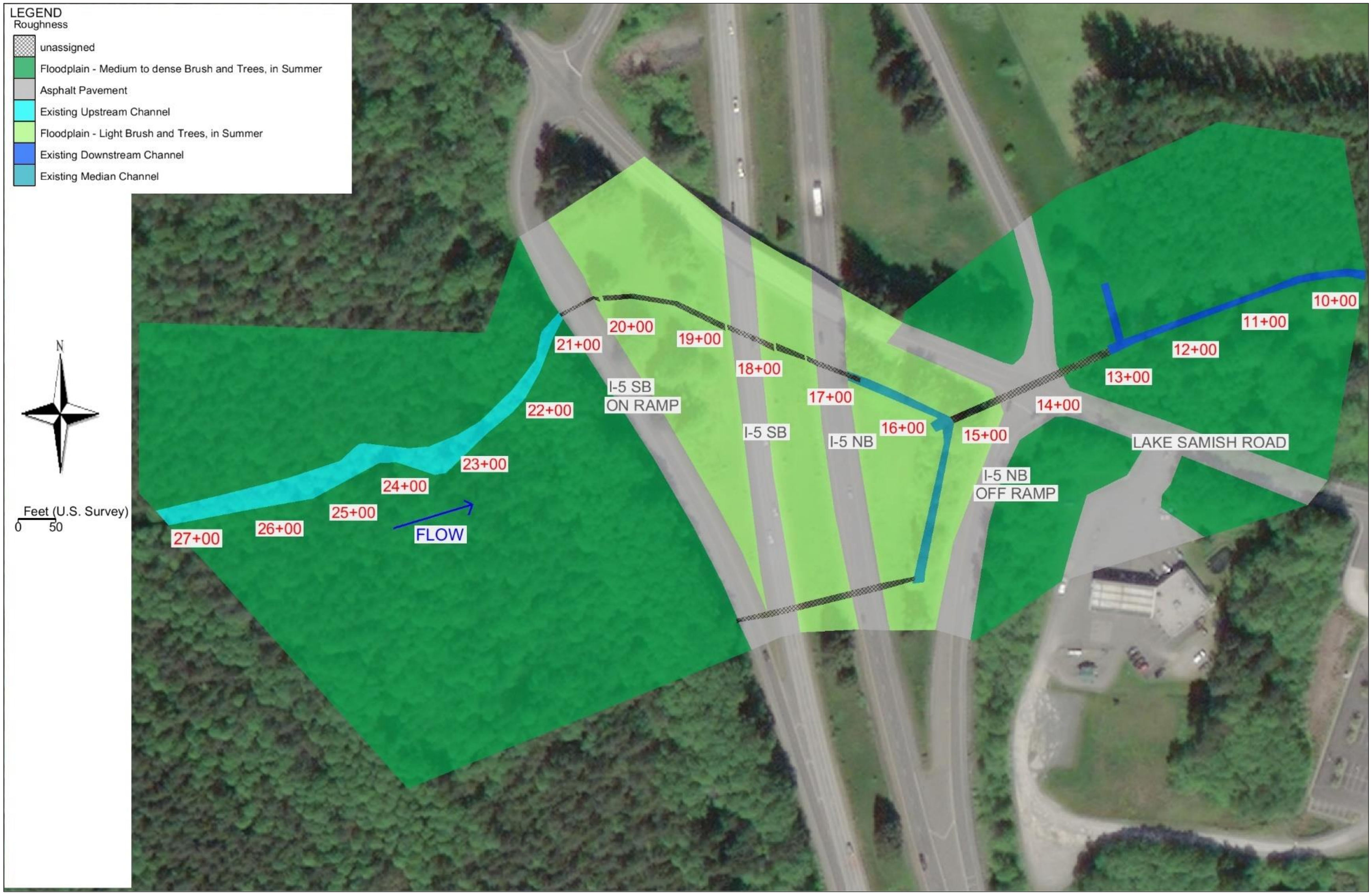


Figure 81: Spatial Distribution of Roughness Values in the Existing Conditions Model

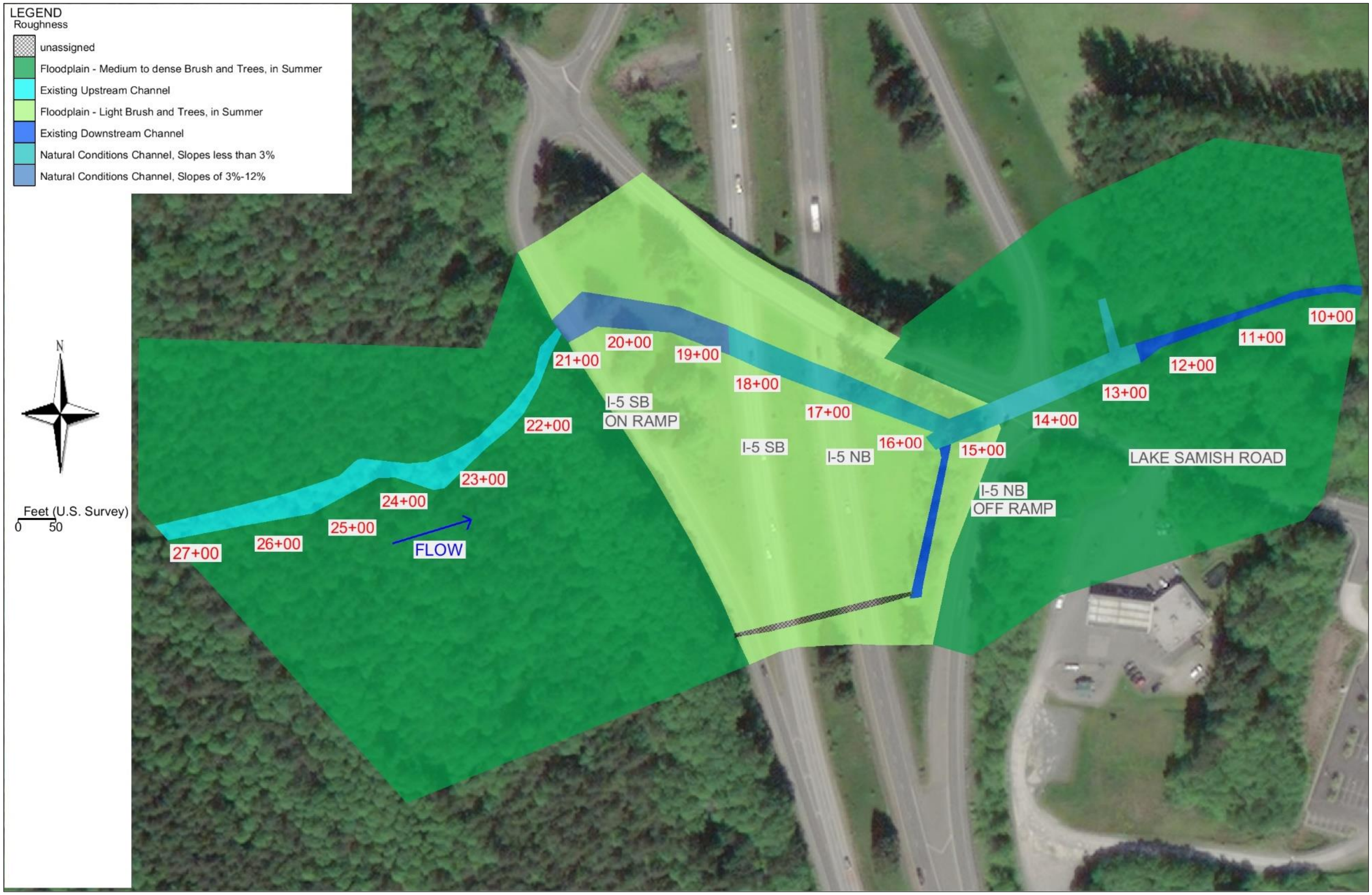


Figure 82: Spatial Distribution of Roughness Values in the Natural Conditions Model

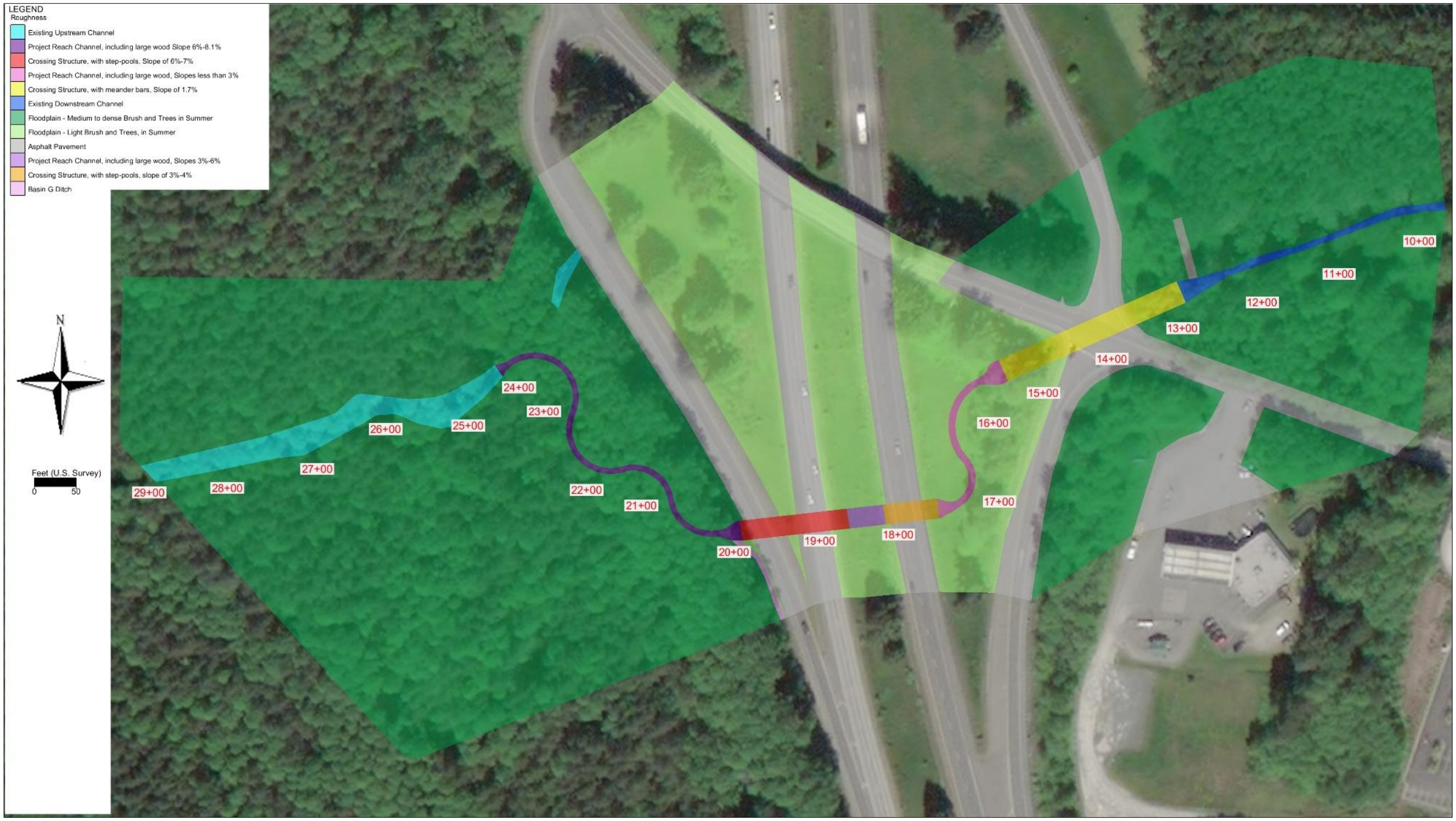


Figure 83: Spatial Distribution of Roughness Values in the Proposed Conditions Model

4.1.4 Boundary Conditions

Existing Conditions

The boundary conditions consisted of inflows at the upstream end of the model and normal depth water surface elevations (WSEs) at the downstream end for the existing conditions models.

For existing conditions, separate steady flow model runs were performed for each of the 2-, 10-, 25-, 50-, 100-, and 500-year discharges to maintain stability of the HY-8 culvert boundary conditions in the model.

An inflow boundary condition was used for South Tributary inflows at the upstream end of the model, approximately 600 feet upstream of Culvert 995236. A second inflow boundary condition was set for the culvert near MP 240.86 that flows to the median on the east side of I-5 (Figure 84) and upstream of the inlet to Culvert 995245 under existing conditions. An additional internal inflow was added within the median on the east side of I-5 to represent runoff from the roadway. Table 20 shows the inflow discharge values used in the models. The annotated map (Figure 84) also shows the inflow boundary conditions setup for the models.

Normal depth WSE boundaries were assigned approximately 300 feet downstream of Culvert 995245 (Figure 92). Overflow at some culvert inlets was observed under existing conditions adjacent to I-5 at some timesteps for large flow events. Therefore, additional outflow boundary conditions were added at the overflow ditches that drain north out of the model domain at these locations (Figure 84). The outflow at the ditches was set to a normal depth water surface boundary condition (Figure 99 and Figure 100).

Geometric data for Culverts 995236 to 995245 were obtained from the survey and were input into HY-8 as shown in Figure 85 through Figure 91. The annotated map (Figure 84) shows the culvert boundary conditions setup for the existing conditions model. The invert elevations for the drainage culvert near MP 240.86 were estimated from field measurements because survey data at this location were not available. The boundary condition for the drainage culvert near MP 240.86 is included in the existing conditions and natural conditions models. Under the proposed conditions model, the culvert at MP 240.86 is removed and replaced by the realignment of the South Tributary and the fish-passage structures.

Table 20: Discharge Values Used in the SRH-2D Model

Flow Event	South Tributary Inflow (cfs)	Inflow to Culvert near MP 240.86 (cfs)	Inflow from Road (cfs)
2-year peak flow	3.1	0.7	2.2
5-year peak flow	5.6	1.3	3
10-year peak flow	7.8	1.8	3.4
25-year peak flow	11.7	2.7	4.2
50-year peak flow	13.6	3.1	5.4
100-year peak flow	14.6	3.4	6.3
2080 predicted 100-year peak flow	17.5	4.1	7.6
500-year peak flow	41.5	9.5	8.4

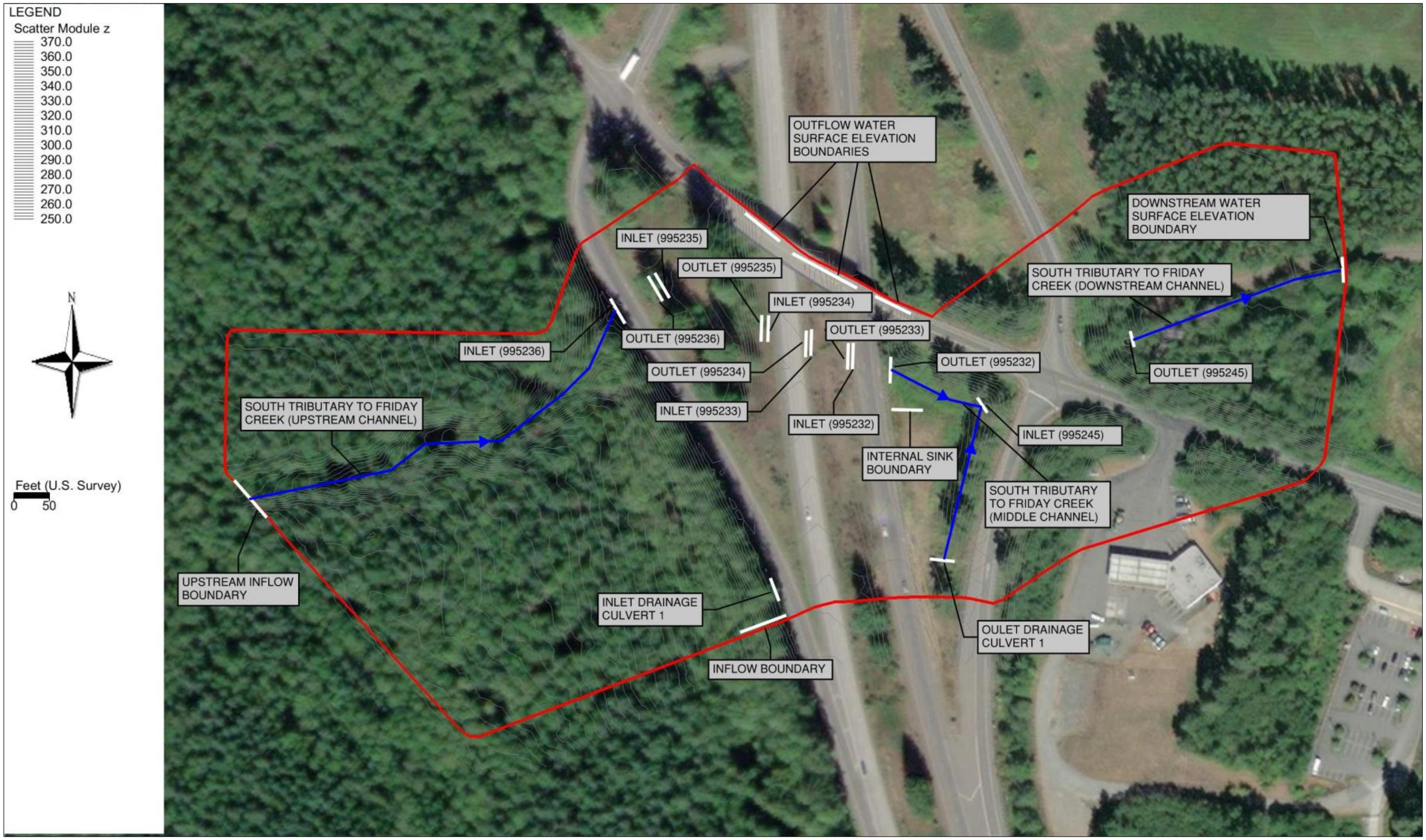


Figure 84: South Tributary Existing Conditions Model Boundary Conditions

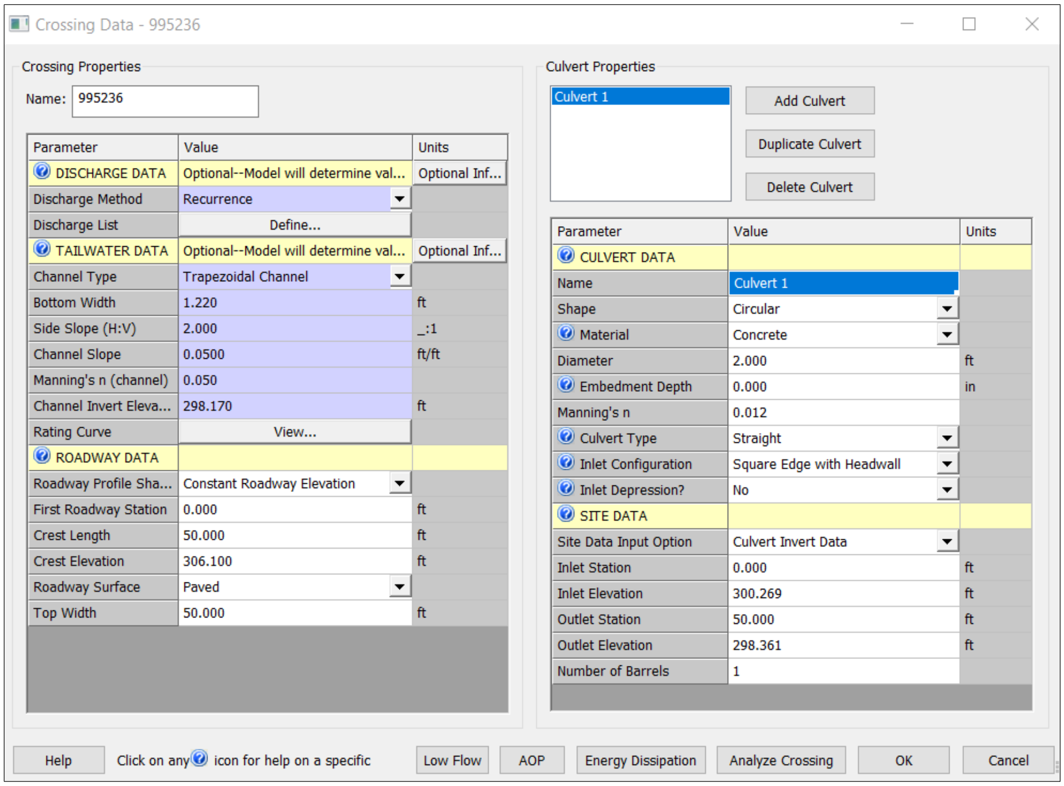


Figure 85: Input Data for HY-8 Boundary Condition Arcs at Culvert 995236

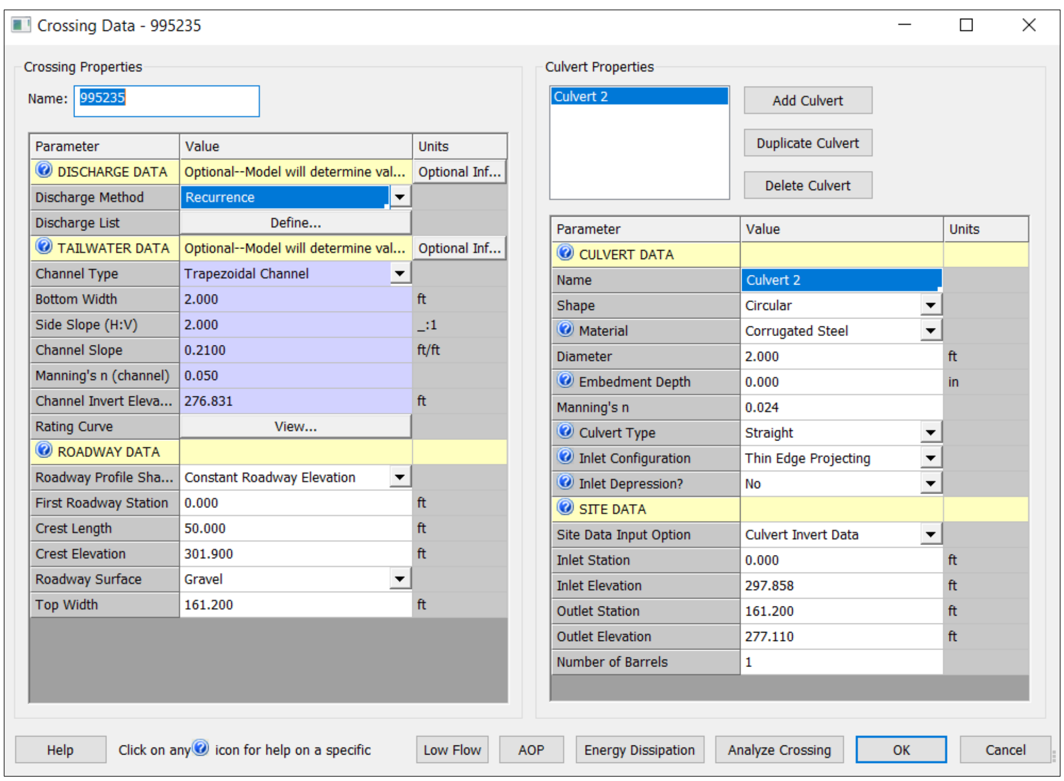


Figure 86: Input Data for HY-8 Boundary Condition Arcs at Culvert 995235

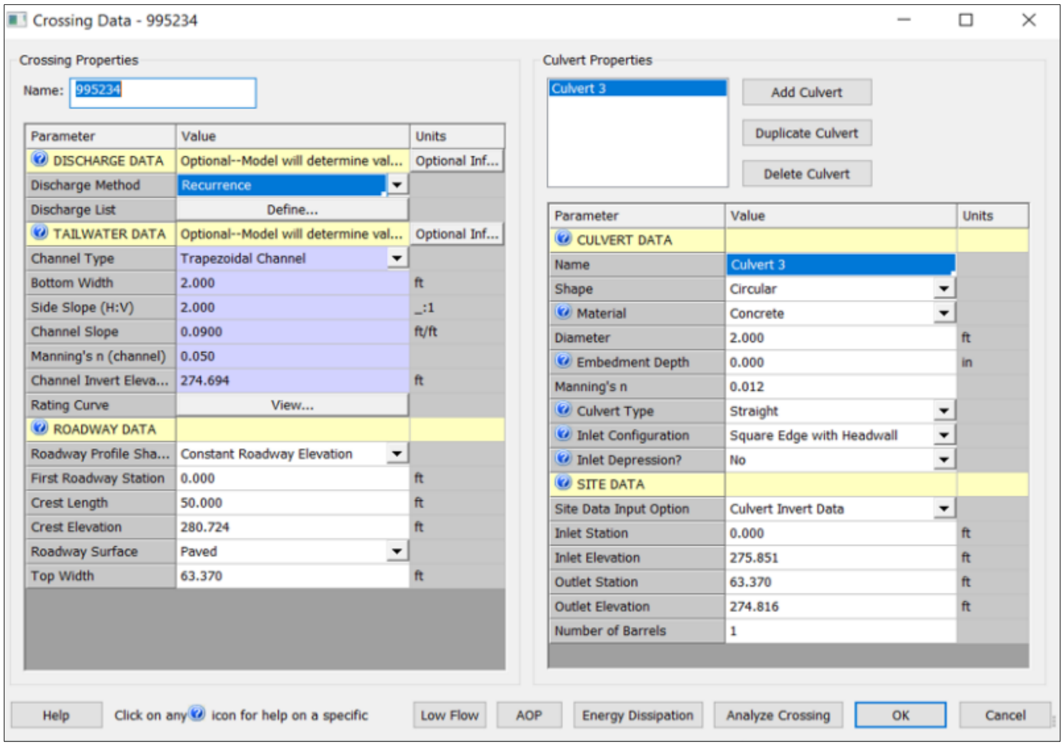


Figure 87: Input Data for HY-8 Boundary Condition Arcs at Culvert 995234

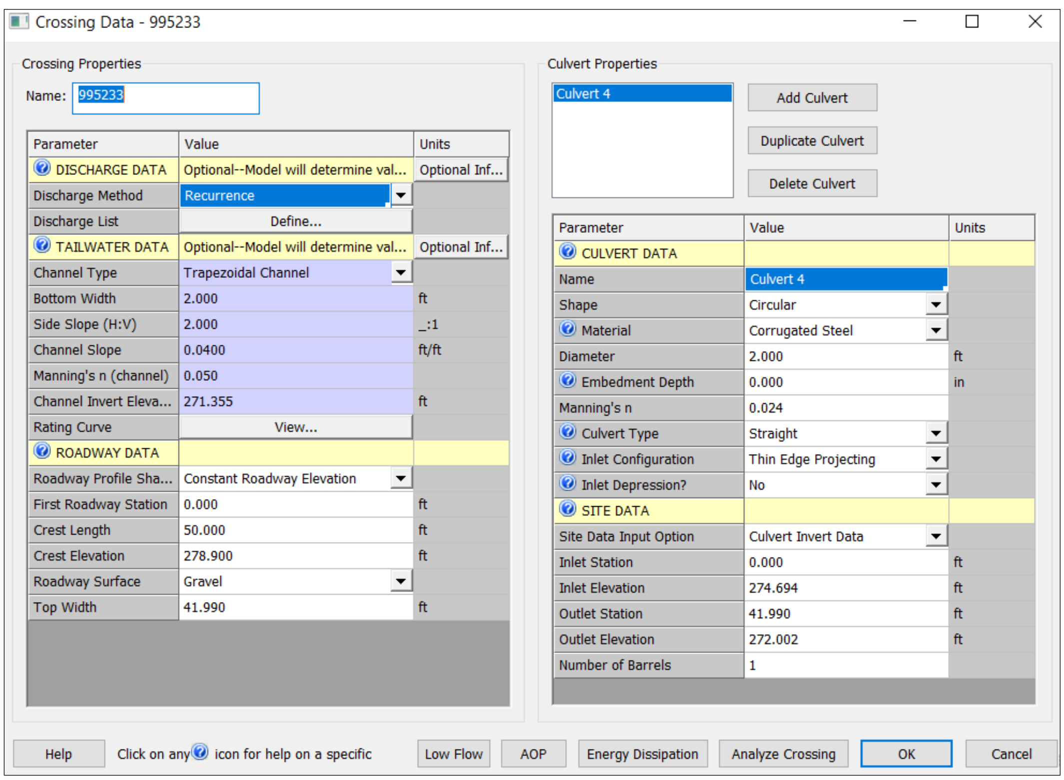


Figure 88: Input Data for HY-8 Boundary Condition Arcs at Culvert 995233

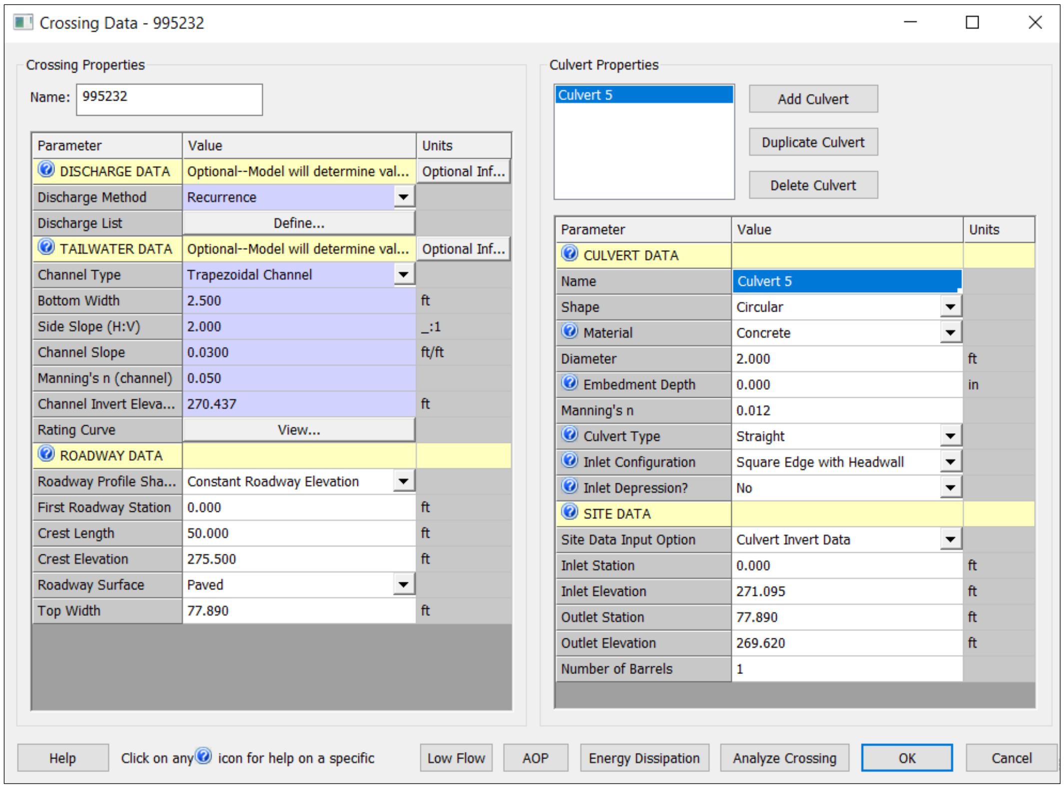


Figure 89: Input Data for HY-8 Boundary Condition Arcs at Culvert 995232

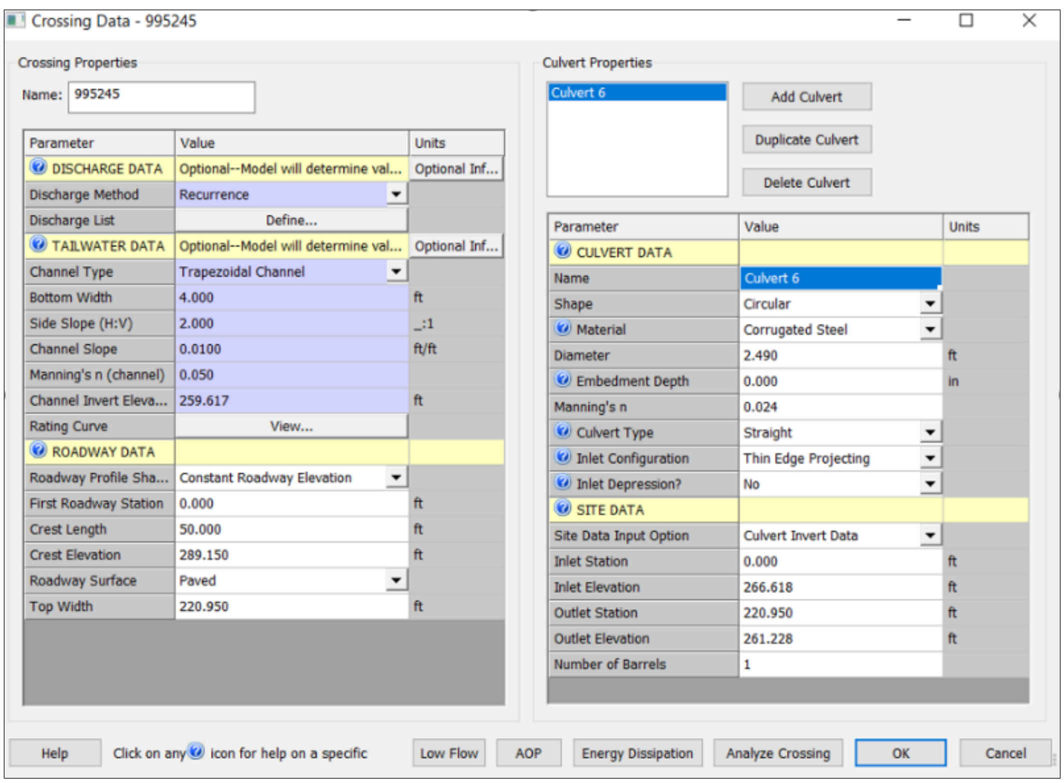


Figure 90: Input Data for HY-8 Boundary Condition Arcs at Culvert 995245

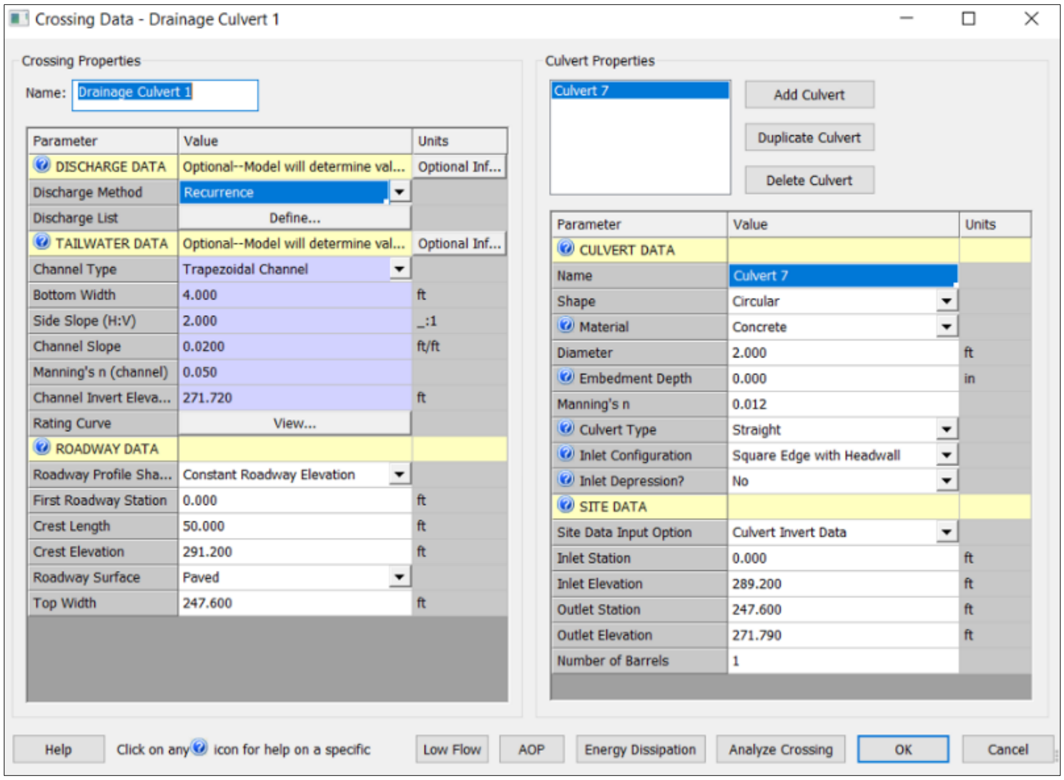


Figure 91: Input Data for HY-8 Boundary Condition Arcs at Culvert near MP 240.86

Natural Conditions

The boundary conditions for the natural conditions model consist of the same boundary conditions as those for the existing conditions model, except with the six barrier culverts removed and replaced with open channel flow. The natural conditions boundary conditions consist of the inflow time series at the upstream end of the model, the internal sink boundary for the roadway runoff, the inflow for the culvert near MP 240.86, the culvert near MP 240.86 inlet and outlet boundaries, the normal depth rating curve for the roadside ditches on the north side of the crossing, and the normal depth rating curve at the downstream end of the model (Figure 92).

The inflow time series for the natural conditions varied in flow rate from the 2-year up through the 500-year peak flows for the values shown in Table 20. Approximately 3 hours of time was simulated between each flow rate to achieve a steady-state solution. The inflow time series is shown in Figure 94 through Figure 96. The normal depth rating curve used a normal depth based on the downstream channel dimensions, slope, and roughness, and is shown in Figure 98.

Proposed Conditions

The boundary conditions for the proposed conditions model are also the same as those for the existing conditions model, but with the six barrier culverts and the culvert near MP 240.86 removed. The proposed conditions boundary conditions consist of the upstream inflow boundary, the internal sink boundary for the roadway runoff, the inflow into the ditch where the culvert near MP 240.86 would be removed, the normal depth rating curves at the roadside ditches to the north, and the normal depth rating curve at the downstream end of the model (Figure 93).

The inflow time series for the proposed conditions also varied in flow rate from the 2-year up through the 500-year peak flows for the values shown in Table 20. Approximately 3 hours of time was simulated between each flow rate to achieve a steady-state solution. The inflow time series is shown in Figure 94 through Figure 96. The SRH-2D channel calculator as shown in Figure 97 was used to determine the normal depth rating curve based on the downstream channel dimensions, slope, and roughness. The downstream normal depth rating curve is shown in Figure 98.

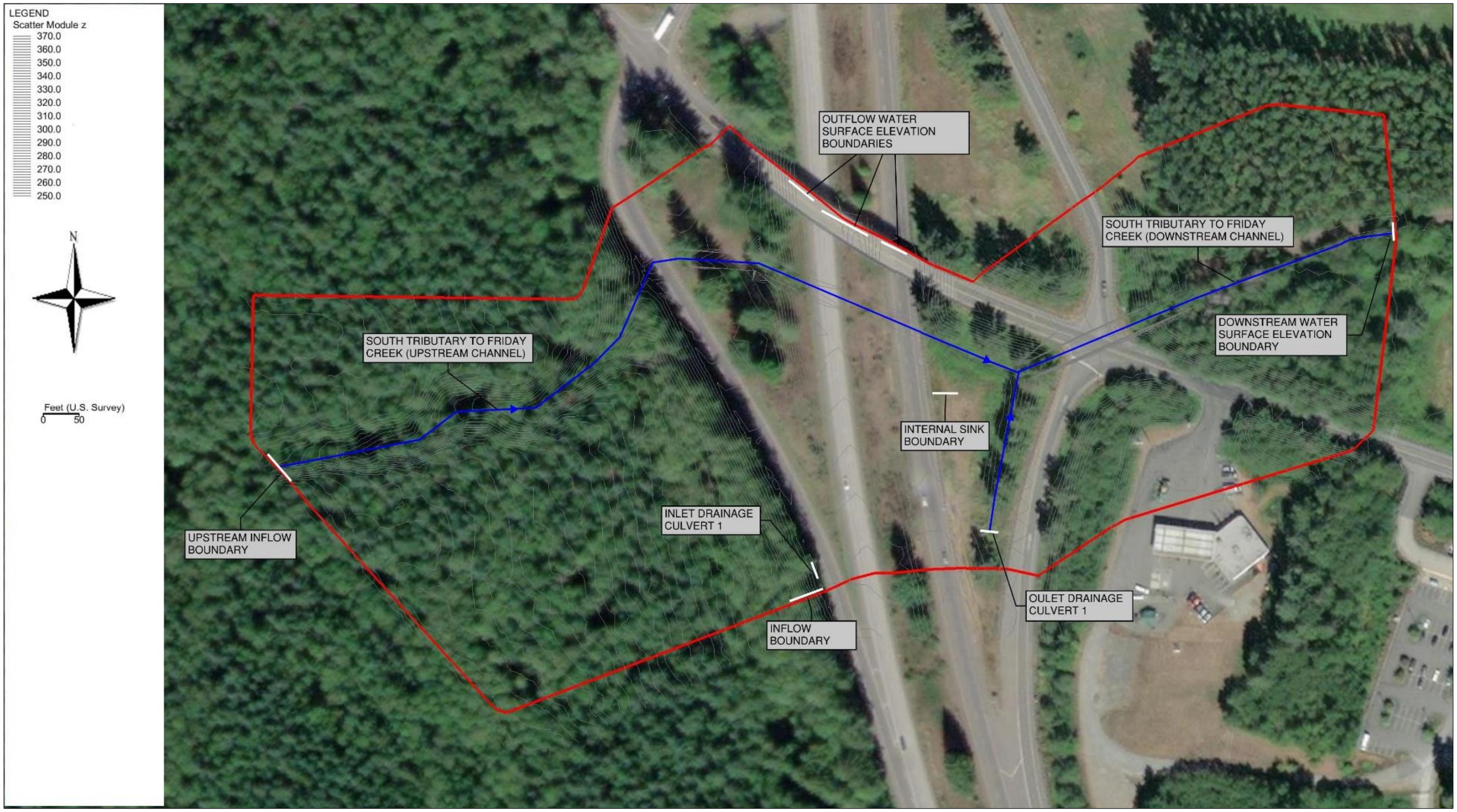


Figure 92: South Tributary Natural Conditions Model Boundary Conditions

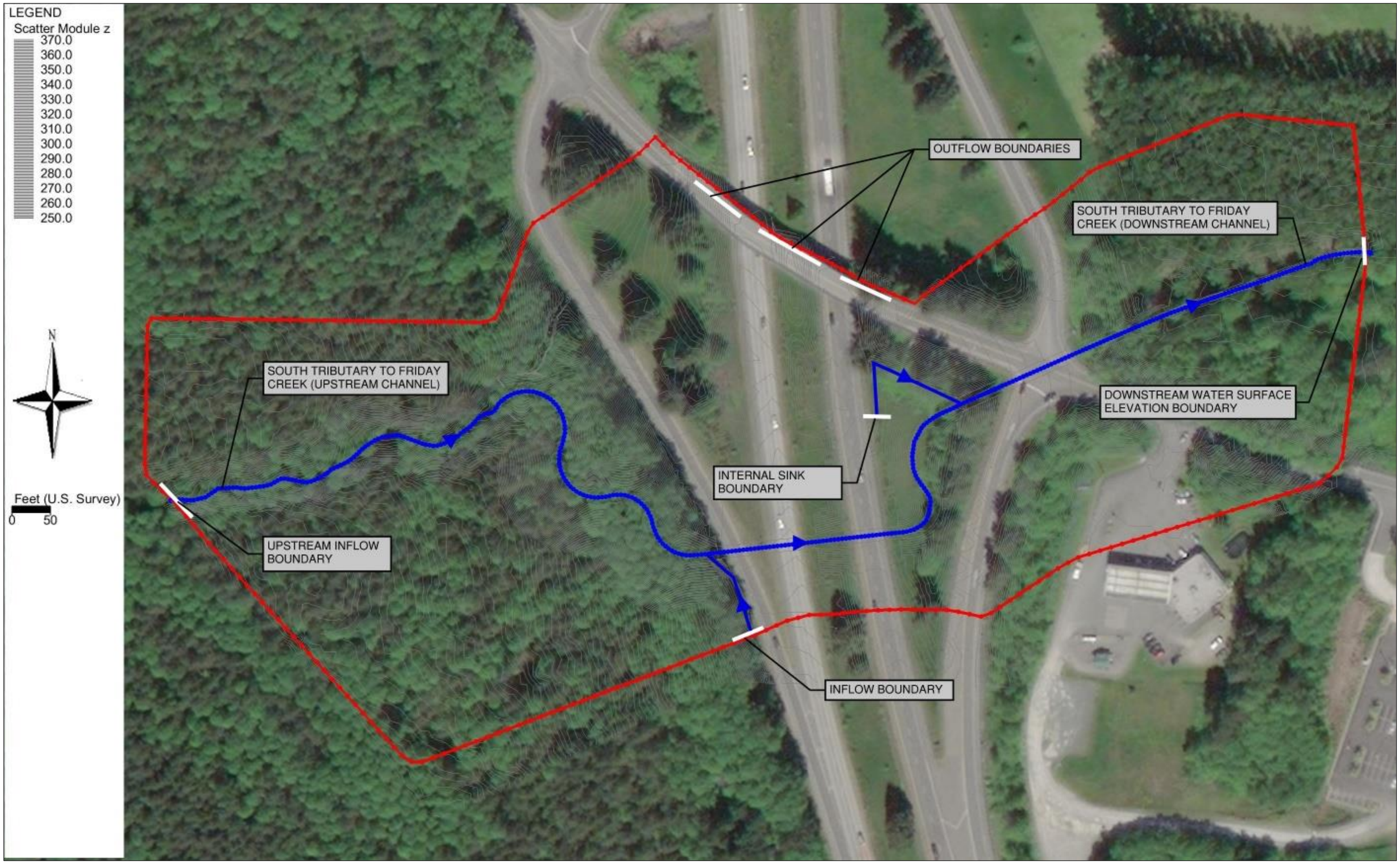


Figure 93: South Tributary Proposed Conditions Model Boundary Conditions

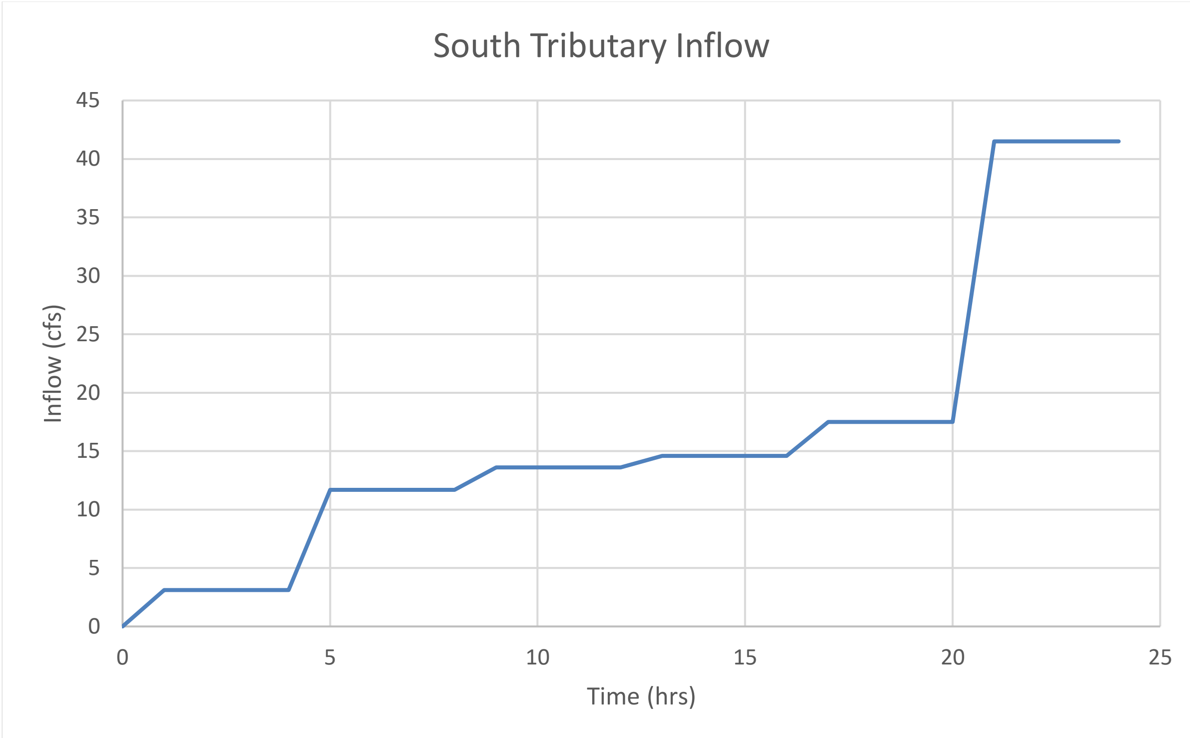


Figure 94: Inflow Boundary Conditions Time Series for the South Tributary Inflow under Natural and Proposed Conditions

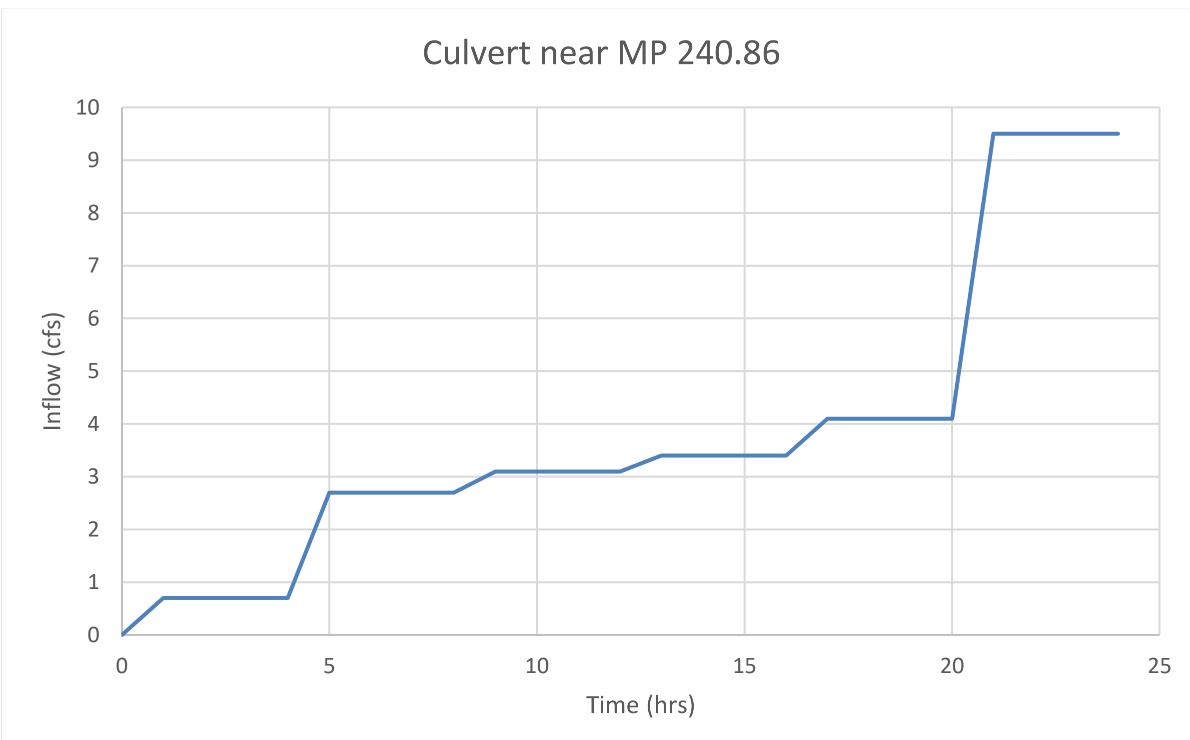
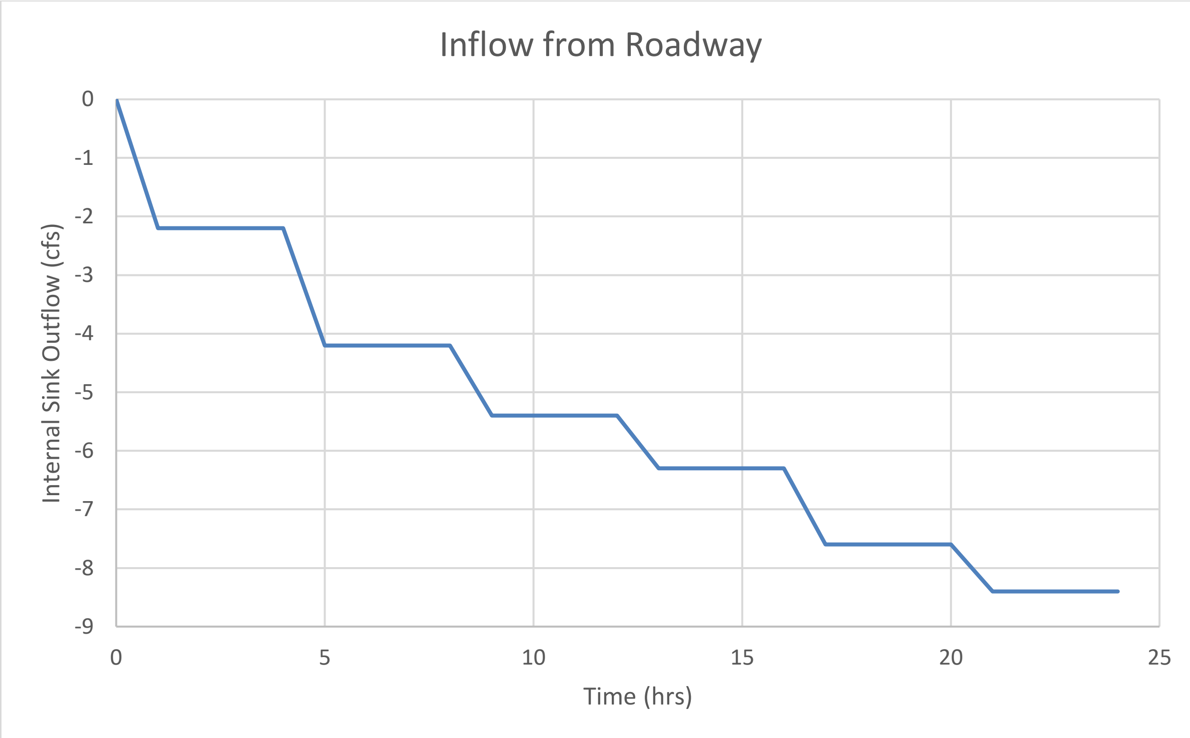


Figure 95: Inflow Boundary Condition Time Series for the Drainage into the Culvert near MP 240.86 under Natural and Proposed Conditions



Note: Negative values for the internal sink boundary in the timeseries above represents flow into the model domain.

Figure 96: Inflow Boundary Conditions Time Series for the Internal Sink for the Inflow from the Roadway Runoff Under Natural and Proposed Conditions

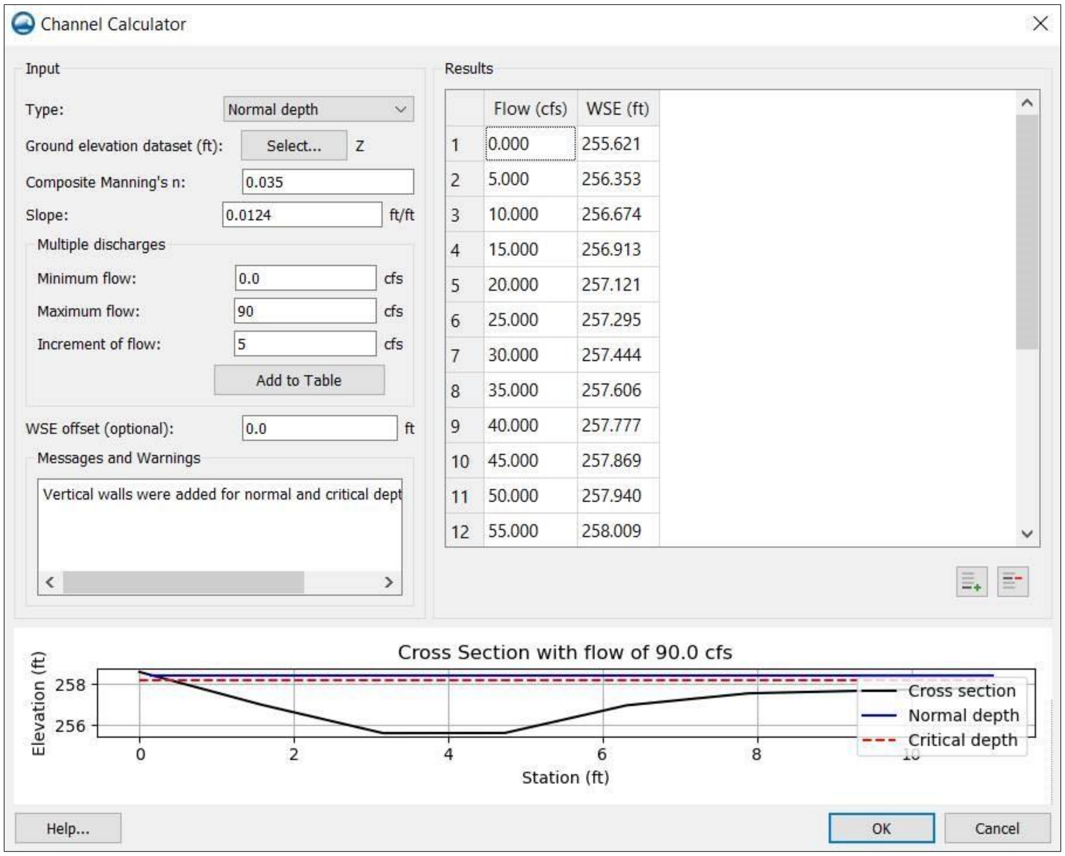


Figure 97: Downstream Normal Depth Boundary Input Data

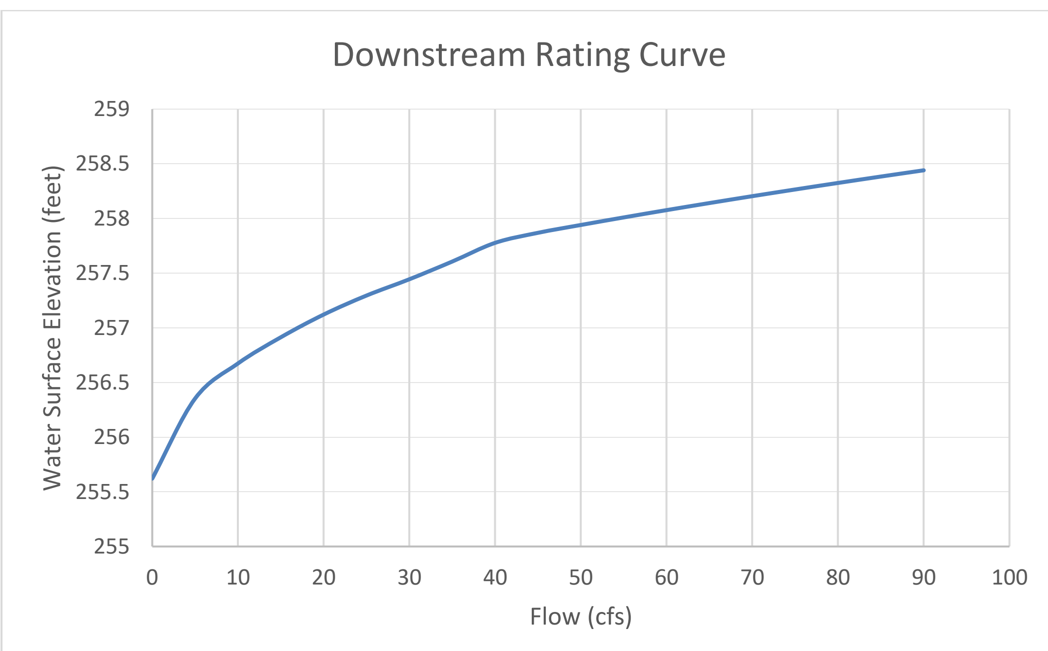


Figure 98: South Tributary Downstream Normal Depth Rating Curve

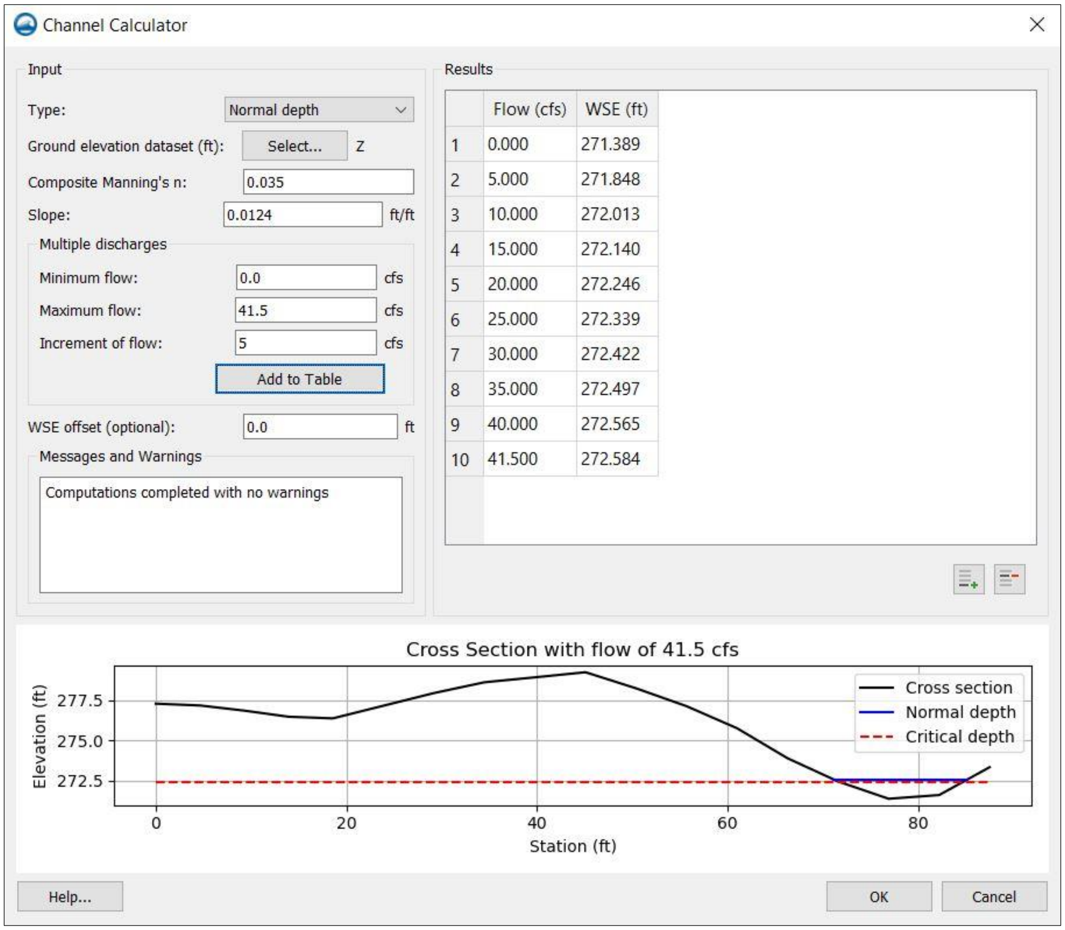


Figure 99: Normal Depth Boundary Condition for North I-5 Roadside Ditch.

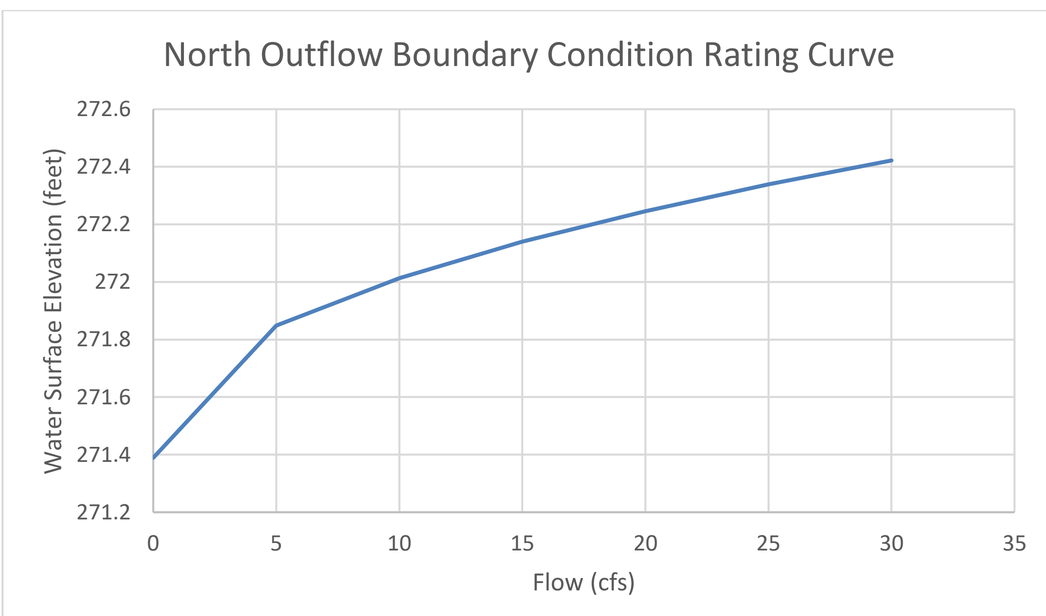


Figure 100: Normal Depth Boundary Condition Rating Curve for North I-5 Roadside Ditch.

4.1.5 Model Run Controls

The existing conditions model was simulated for a 4-hour duration, with a time step of 0.5 second, for each of the flows. The simulation time was set to allow the model to achieve a steady-state solution by the end of the simulation. The initial condition for the model start-up was set to a dry initial condition which assumes no flow in the stream at the start of the simulation. The monitor line output data was reviewed to determine that the model reached a steady-state solution for each of the simulated flows.

For the natural conditions and proposed conditions models, the simulation time was 24 hours to model flows from the 2-year through the 500-year peak flow. The timestep was set to 0.5 second, with a dry initial condition. The monitor lines were reviewed to determine that a steady-state solution was reached at the end of each 3-hour interval between flow rates.

4.1.6 Model Assumptions and Limitations

No additional assumptions or limitations were made, other than those described in previous sections.

4.2 Existing Conditions Model Results

Cross sections were extracted in three locations in the existing conditions model (Station [Sta.] 11+68, Sta. 6+57, and Sta. 1+92) to represent the Upstream Reach, the Project Reach, and Downstream Reach, respectively (Figure 101). The stationing for the model was set to start at Sta. 10+00 at the downstream end of the model domain to match the preliminary plan stationing (Figure 102). The existing conditions model results indicate that the stream flows at a shallow depth (0.3 foot to 0.6 foot average depth) with velocities in the 1.6 to 2.6 feet per second (ft/sec) range for the 2-year and 100-year peak flows, respectively, in the Upstream Reference Reach where the slope is around 8.1 percent (Table 21). See Appendix C for the SRH-2D model results.

The average modeled flow depth across the channel, including side slopes, was 0.3 foot, while the flow depth at the channel thalweg (maximum depth) was modeled as about 0.5 foot for the 2-year peak flow. These flow conditions generally match the observed conditions in the Upstream Reach found during typical flows in the stream assessment in January 2021. Deeper flows are observed within pools, but flow depths are often shallower on average due to the riffles within the steep Upstream Reach.

The Upstream Reach of the South Tributary is also an incised channel on a steep slope; therefore, the modeled flow depths are lower than the field measured bankfull depths. A greater than 100-year flow is likely required to reach the bankfull depth measured in the field. The channel incision resulting in no modeled floodplain engagement until greater than the 100-year flow occurs in the Upstream Reference Reach. The Reference Reach received concurrence for the BFW measurements with the comanagers, and the model appears to represent the natural stream processes, which include limited floodplain engagement due to channel incision. As shown in Table 22, the floodplain velocities for the Upstream Reach, Project Reach, and Downstream Reach are 0 ft/s as the banks do not overtop.

In the Downstream Reach where slopes are about 1.4 percent, the flows remain shallow (0.2- to 0.8-foot depth) but with higher velocities (2.1 to 4.8 ft/sec) for the 2-year and 100-year peak flows, respectively, due to the lower roughness. The existing conditions flow profiles are shown in Figure 103 through Figure 105.

The cross section results show that the 100-year water surface is only slightly wider than the 2-year water surface, indicating the tributary is confined under existing conditions (Figure 106 through Figure 110). The 2-year and 100-year flow widths are not as wide or as deep as the BFWs and depths measured in the Upstream Reference Reach.

The 100-year velocity maps (Figure 111 through Figure 113) indicate that velocities are in the range of 2 to 5 ft/sec upstream and increase downstream of the culverts due to the lower roughness conditions. A velocity of about 8 ft/sec is shown at the outlet of the downstream culvert (995245), corresponding to the location of the scour pool observed during the field assessment. The existing conditions model results indicate that ponding can occur in the roadside ditches that drain north, adjacent to the culvert outlets and inlets on both sides of I-5 southbound and I-5 northbound based on the existing six culverts under the interchange. During the 100-year event under existing conditions, the flow is shown as overtopping into the ditch to the north along I-5 at the Culvert 995233 inlet. Observations from December 2021 and January 2022 found that the South Tributary had deposited sediment at the Culvert 995232 inlet and was flowing north into the ditch at the Culvert 995232 inlet location.

The shear stress is higher in the Upstream Reach and is much lower downstream (Table 21) due to the lower slopes. Sediment transport capacity is higher in the Upstream Reach (a transport reach), and the Downstream Reach has a much lower capacity for transporting sediment (a response reach). As a result, sediment aggradation can be expected in the Downstream Reach. This corresponds to the observed sand inundating the outlet of Culvert 995232 under I-5 northbound.

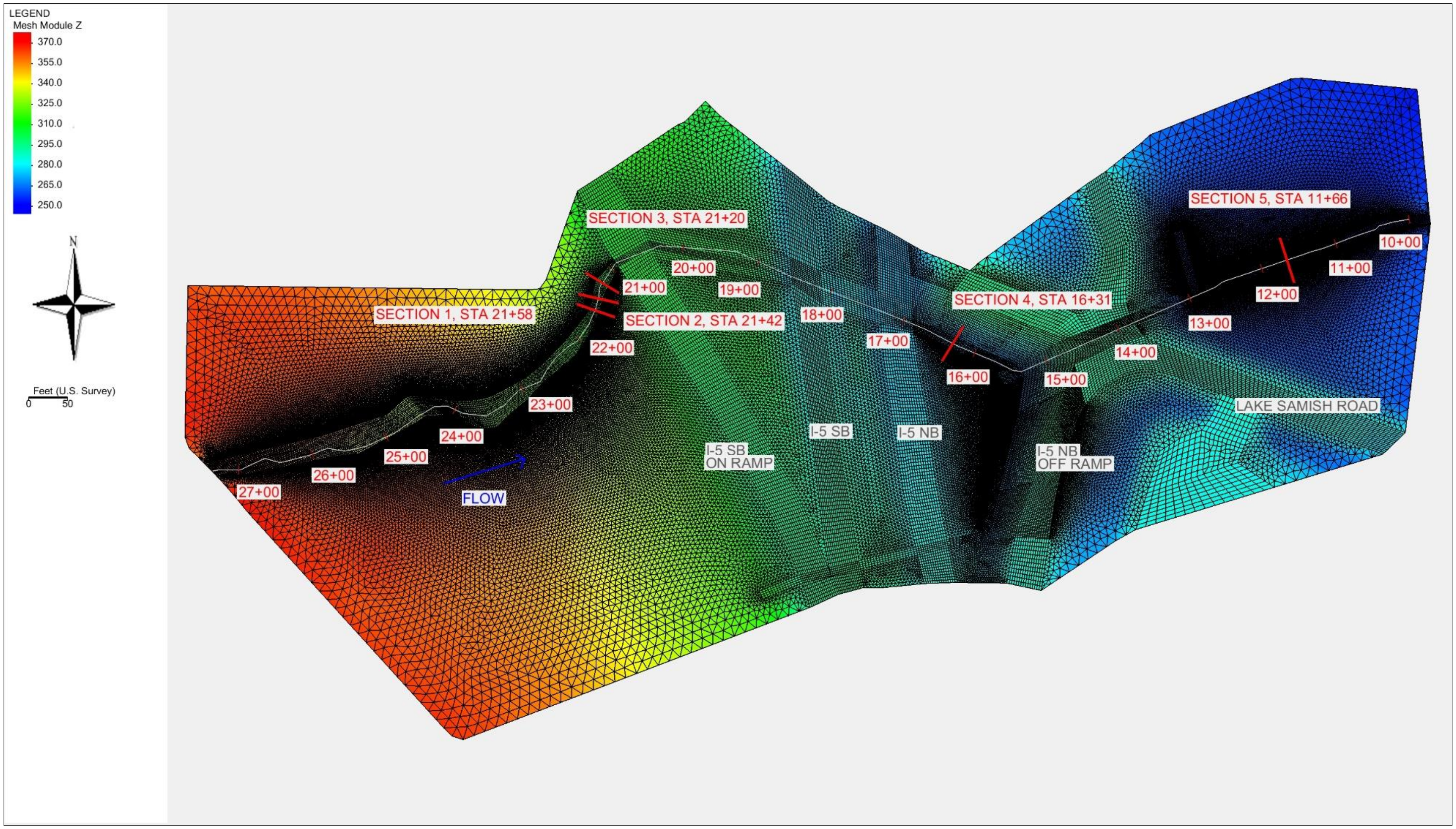


Figure 101: South Tributary Locations of Cross Sections Used for Existing Conditions Results Reporting

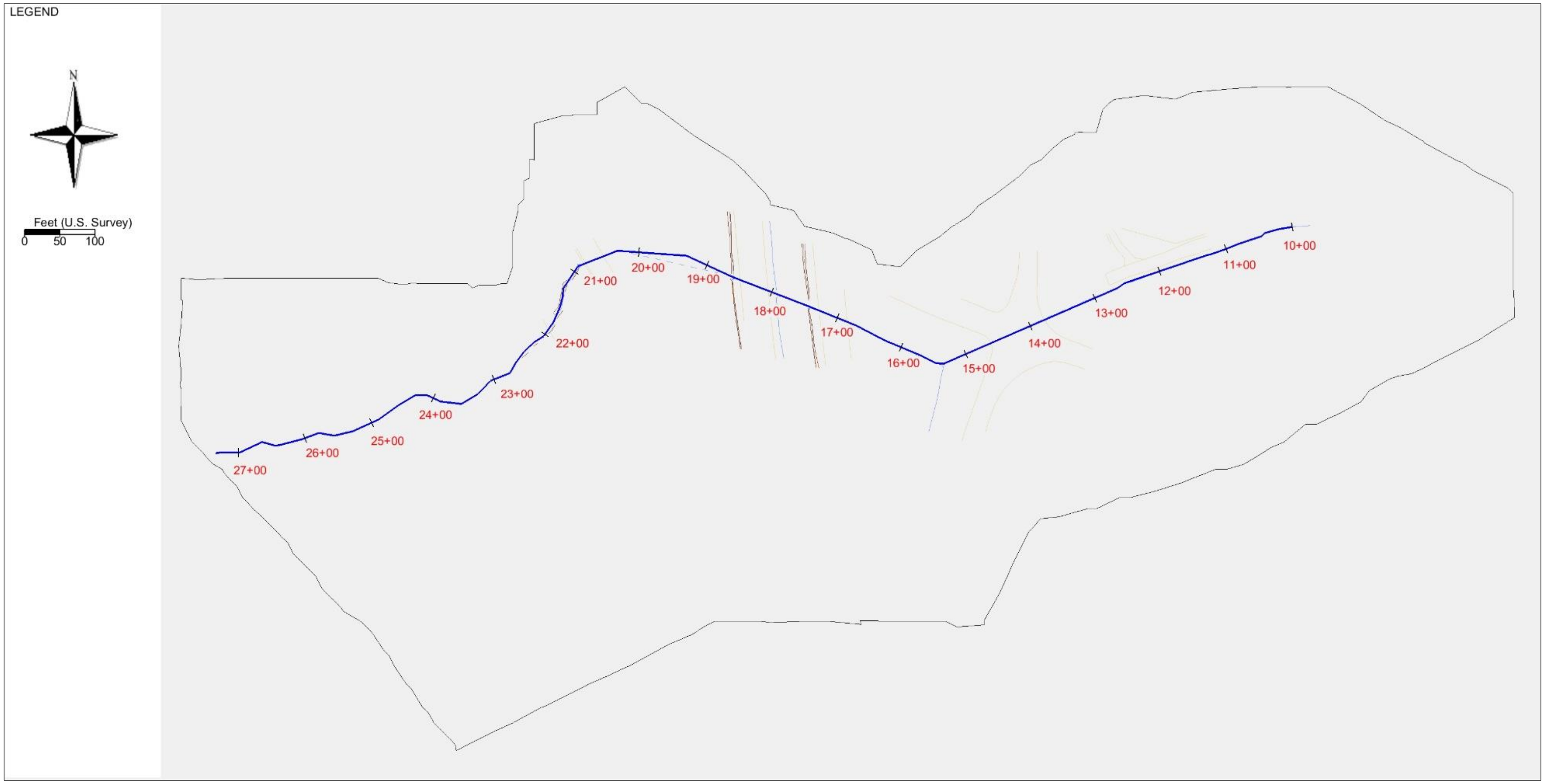


Figure 102: Longitudinal Profile Stationing for Existing Conditions

Table 21: Average Hydraulic Results for Existing Conditions

Event Years	WSE (feet)		Depth (feet)		Velocity (ft/sec)		Shear (lb/ft^2)	
	US	DS	US	DS	US	DS	US	DS
2	306.1	258.8	0.3	0.2	1.6	2.1	1.7	0.2
100	306.5	259.8	0.6	0.8	2.6	4.8	3.6	0.7
500	307.0	260.2	1.1	1.3	3.8	4.9	6.7	0.7

Upstream cross section = Station 21+42

Downstream cross section = Station 11+66

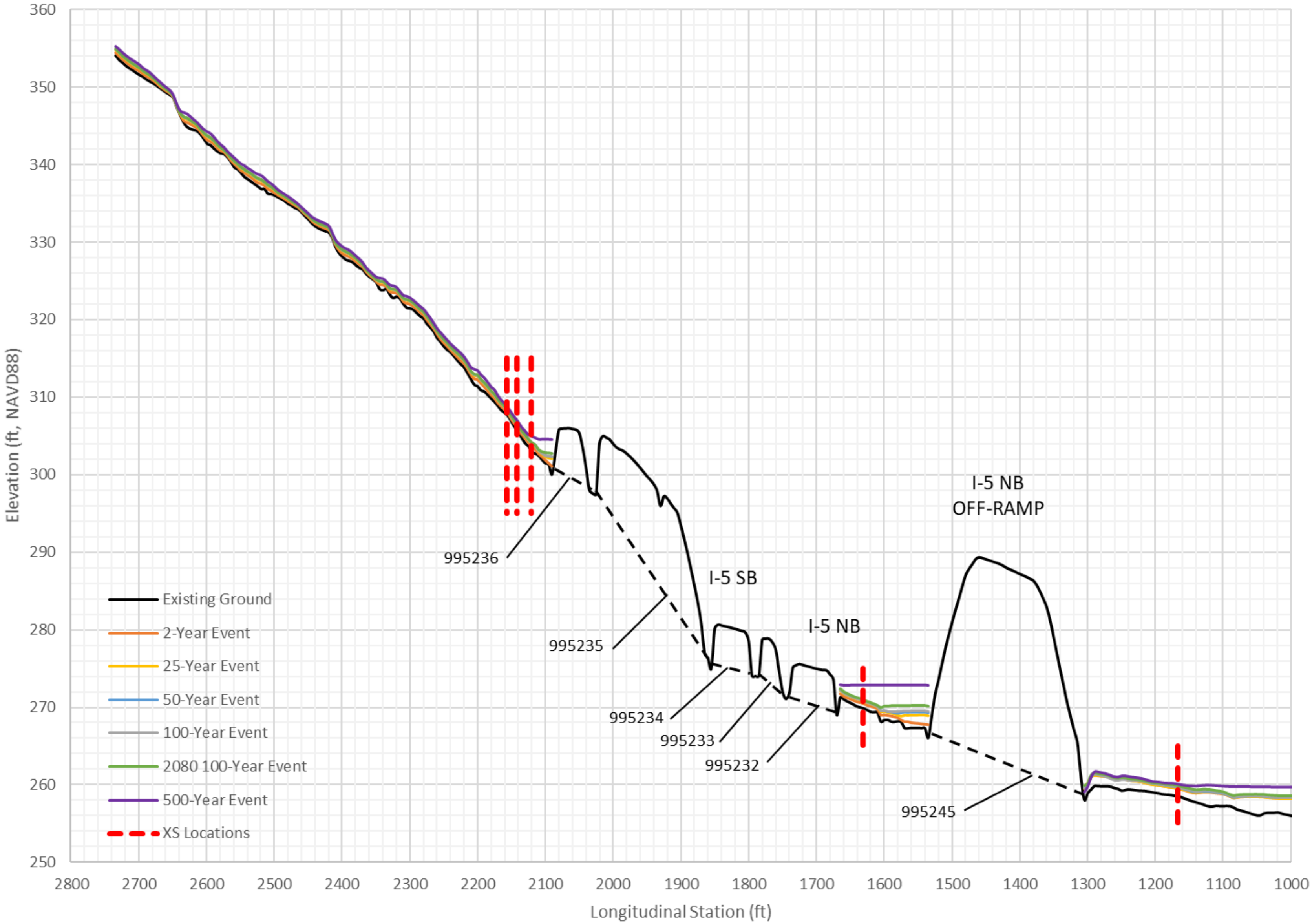


Figure 103: Existing Conditions Water Surface Profiles (overall)

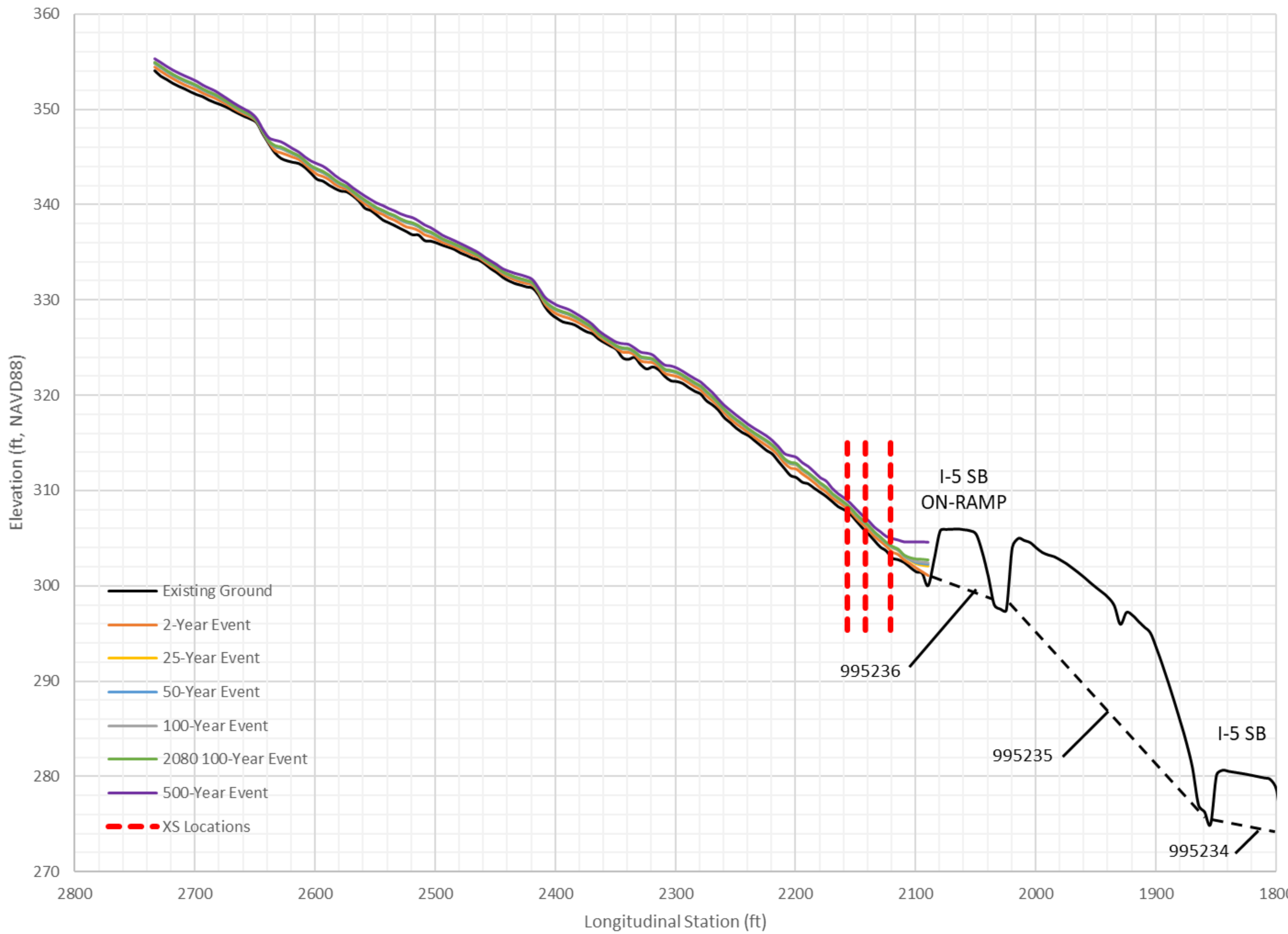


Figure 104: Existing Conditions Water Surface Profiles (upstream)

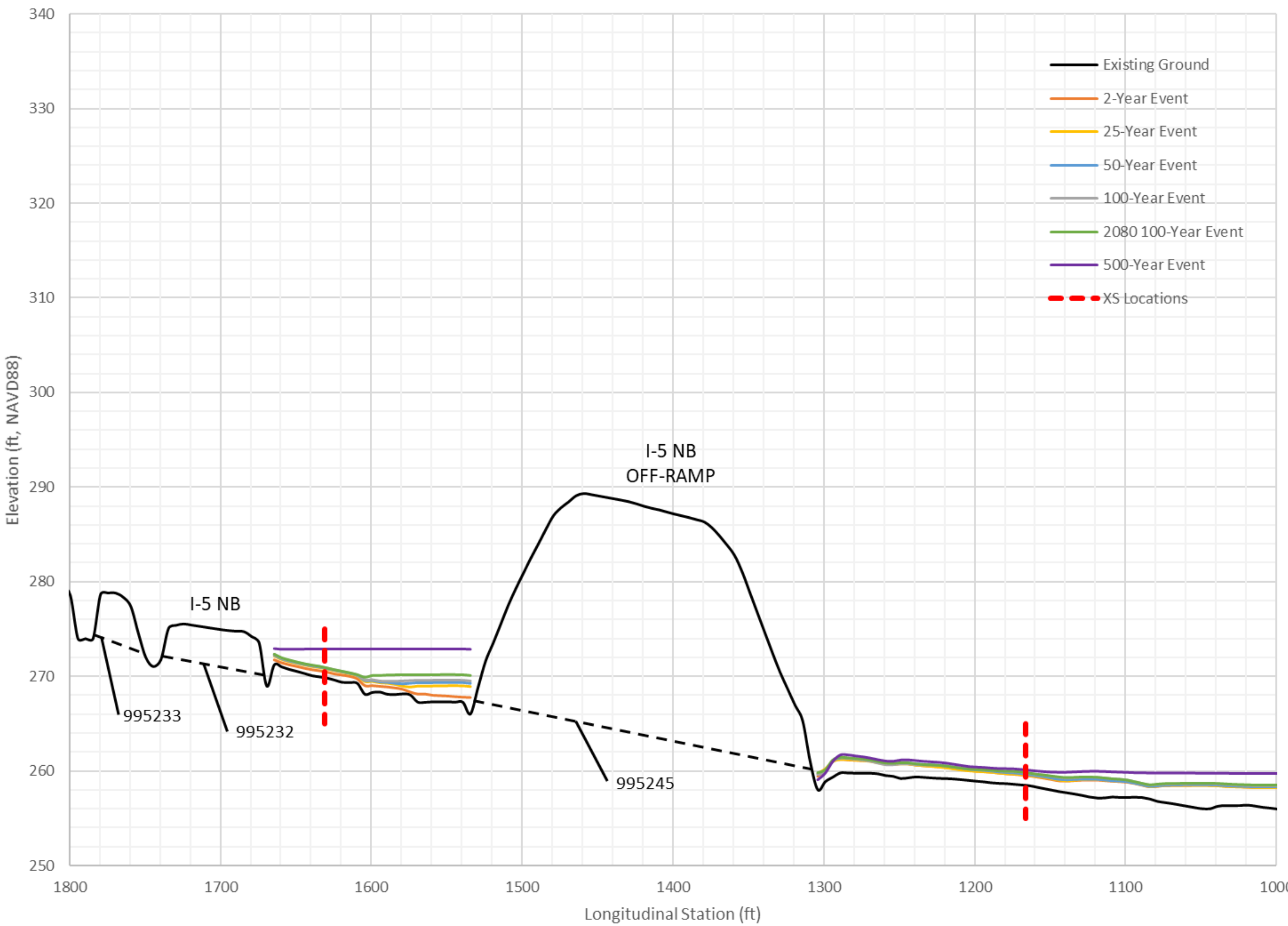


Figure 105: Existing Conditions Water Surface Profiles (downstream)

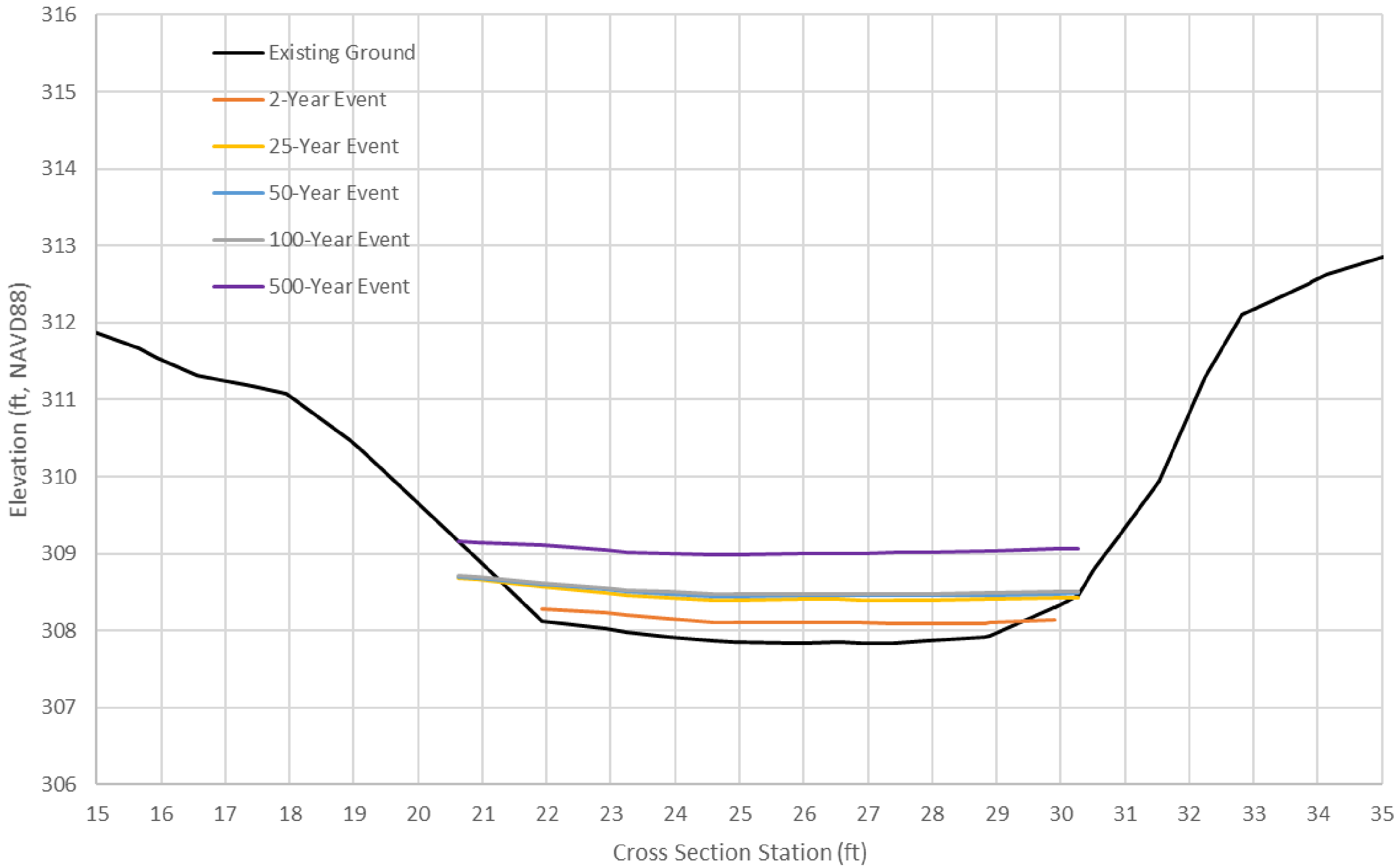


Figure 106: Existing Upstream Channel Cross Section (Sta. 21+58)

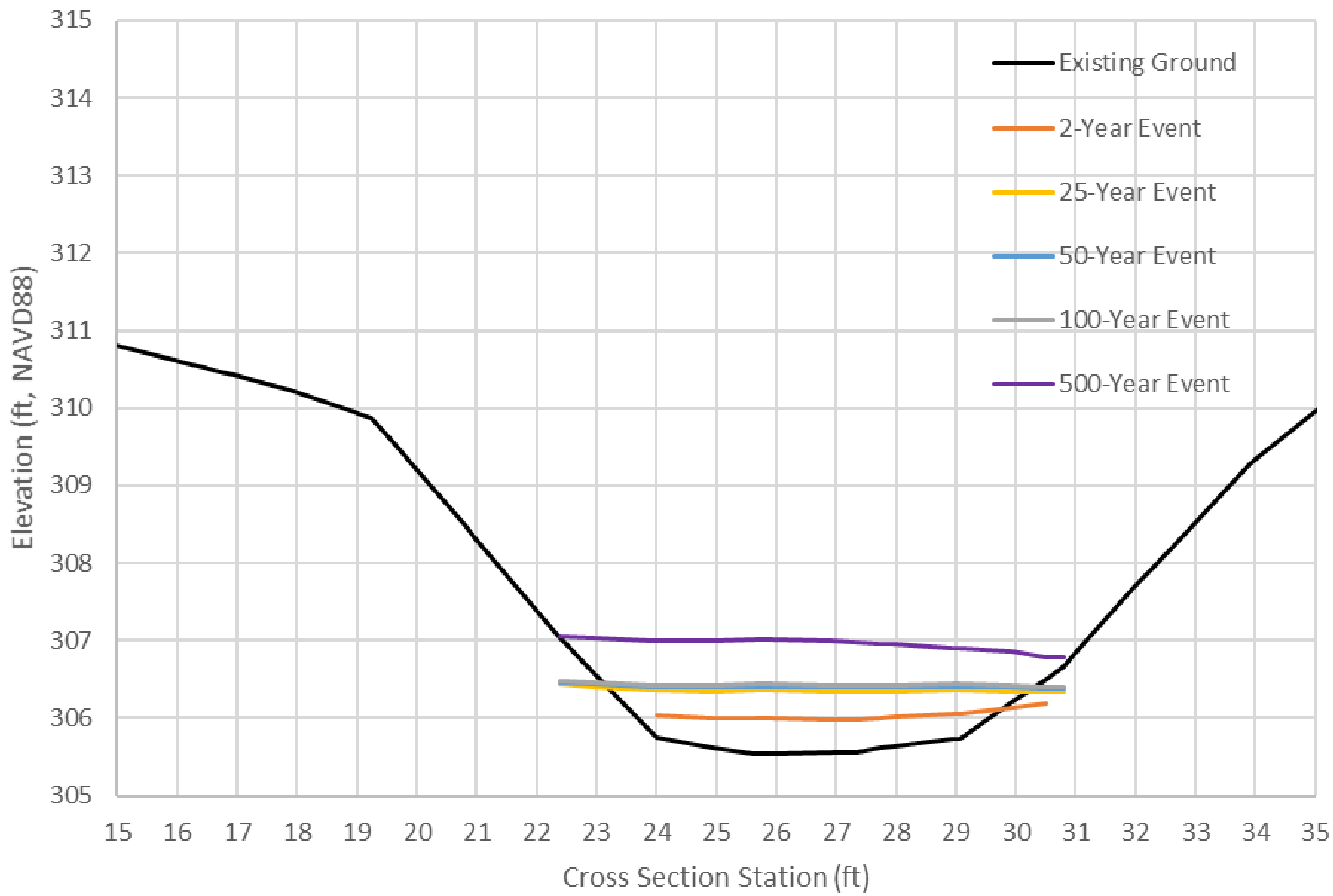


Figure 107: Existing Upstream Channel Cross Section (Sta. 21+42)

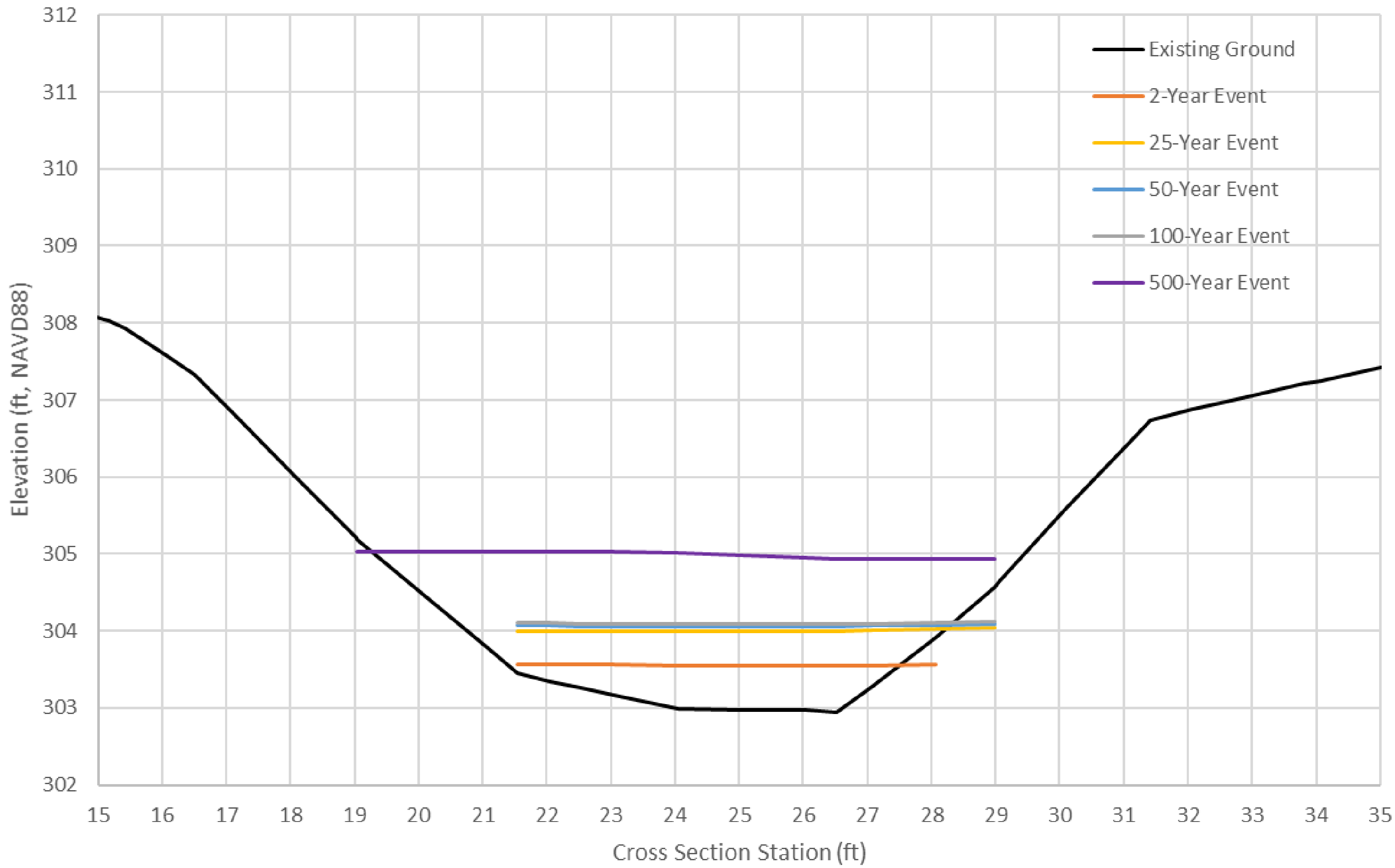


Figure 108: Existing Upstream Channel Cross Section (Sta. 21+20)

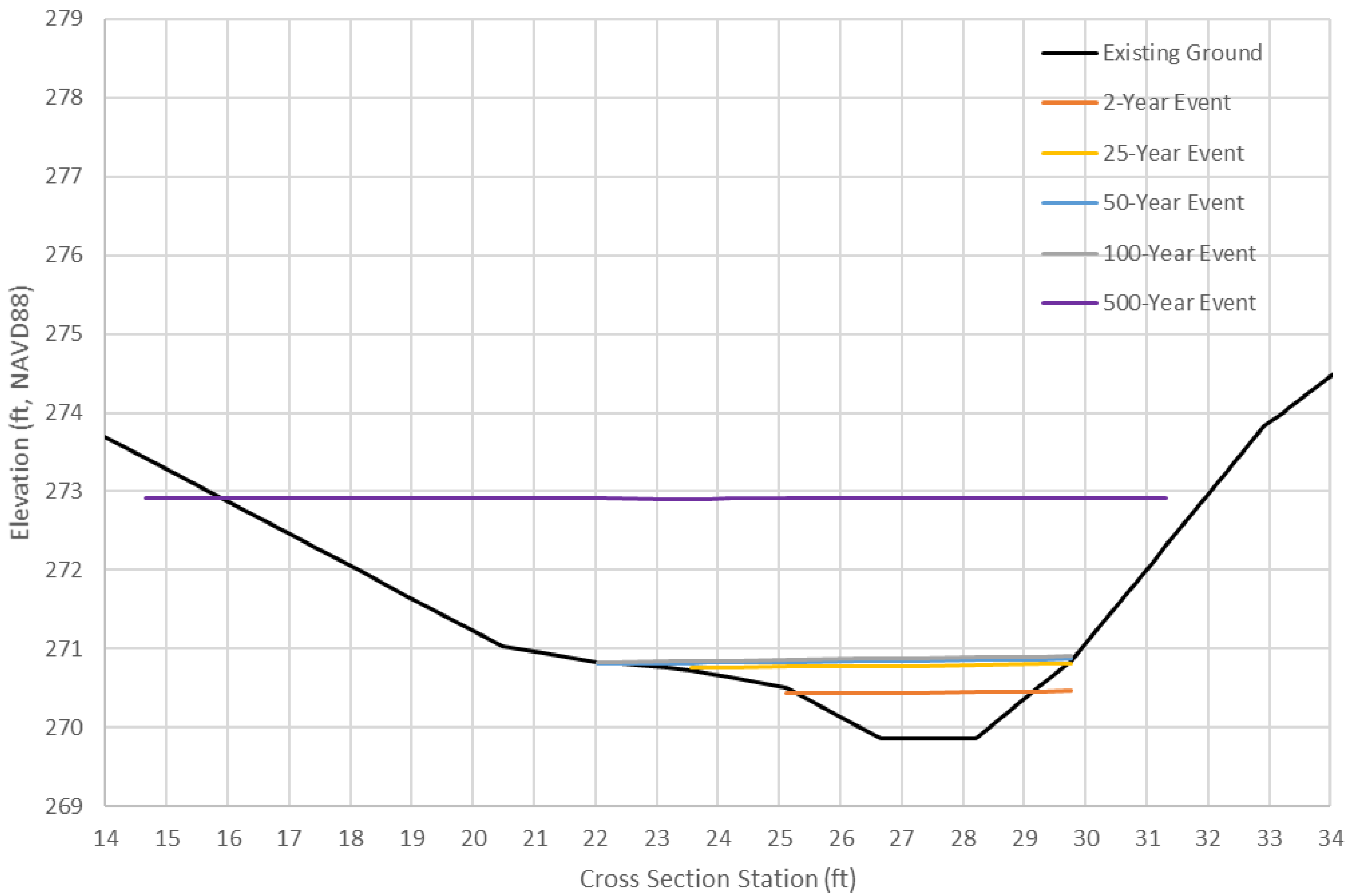


Figure 109: Typical Existing Cross Section Within Median (Sta. 16+31)

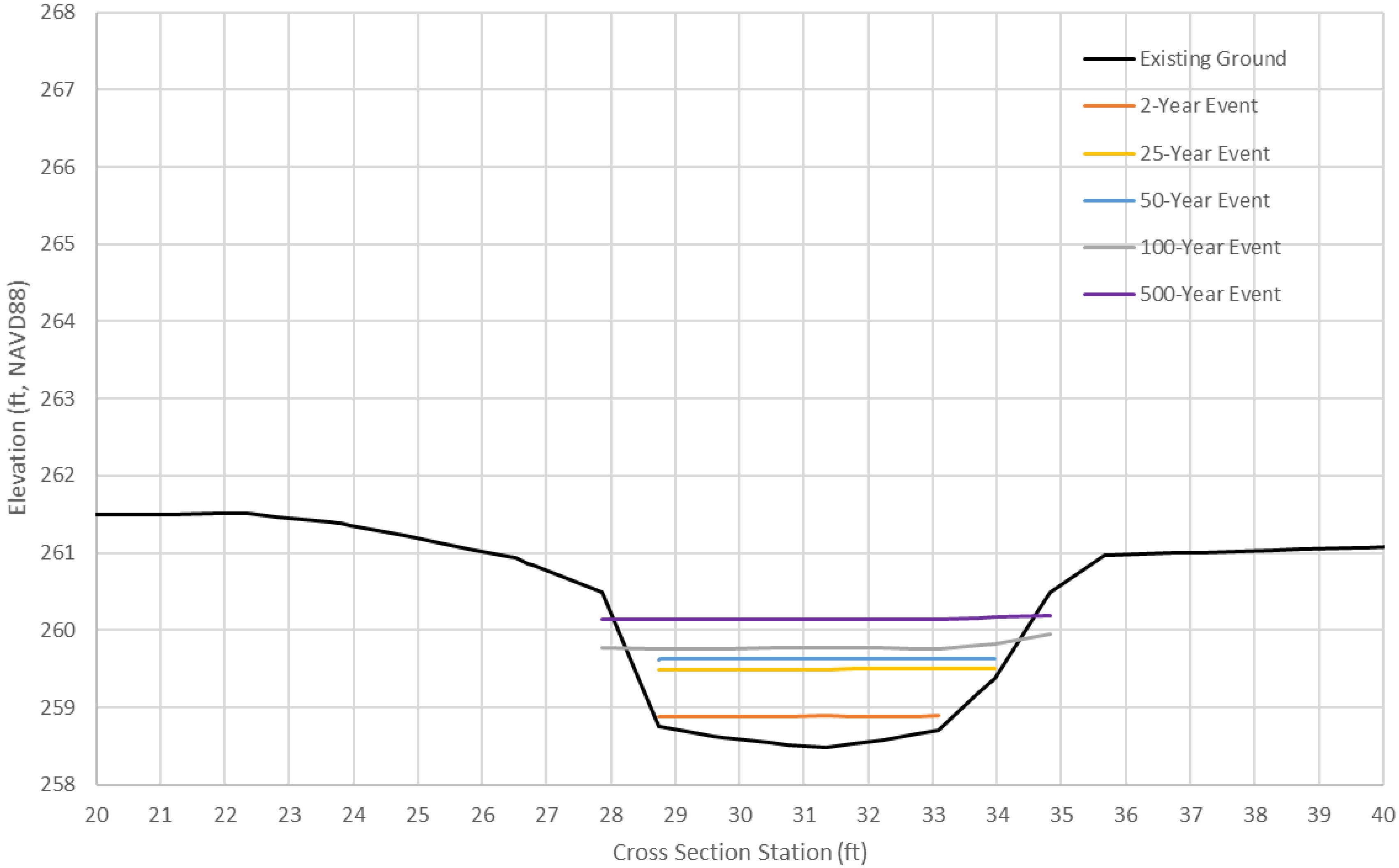


Figure 110: Typical Existing Downstream Channel Cross Section (Sta. 11+66)

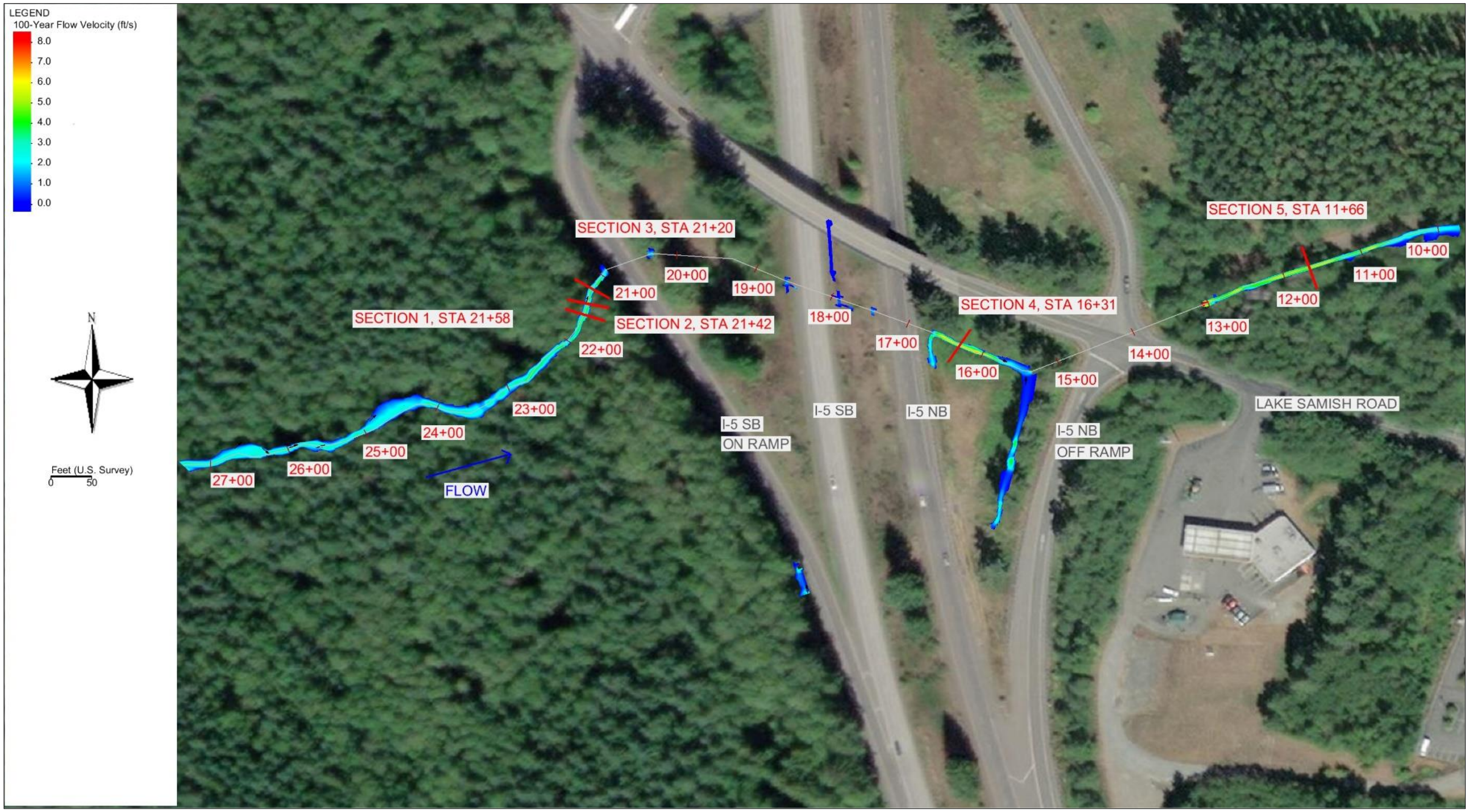


Figure 111: Existing Conditions 100-Year Velocity Map with Cross Section Locations

Figure 112: Existing Conditions 100-Year Velocity Map with Cross Section Locations (upstream)

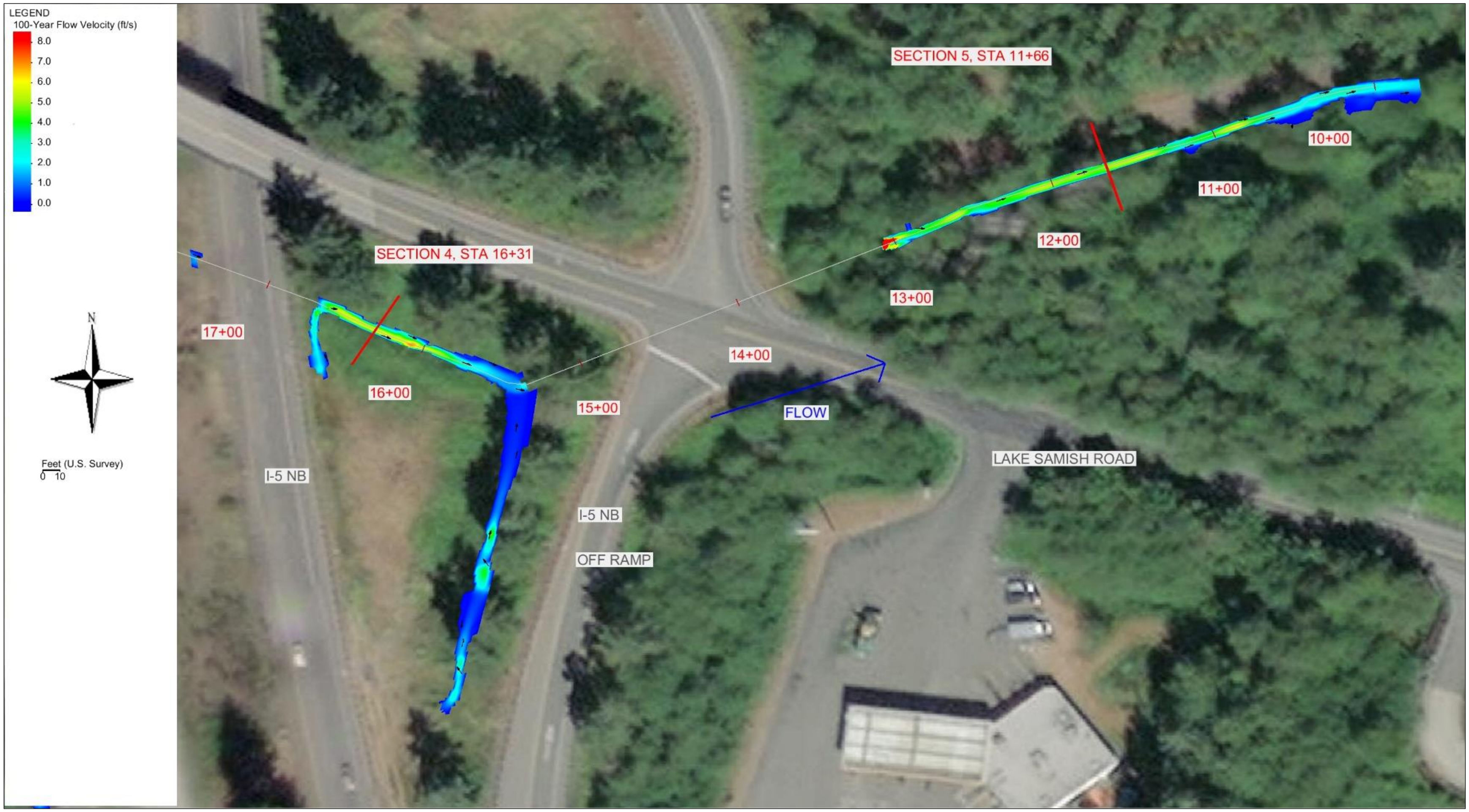


Figure 113: Existing Conditions 100-Year Velocity Map with Cross Section Locations (downstream)

Table 22: Existing Conditions Velocities Including Floodplains at Select Cross Sections

	Q100 Average Velocities (ft/sec)		
	Left Overbank[a]	Main Channel	Right Overbank[a]
Upstream Reach	0	2.6	0
Project Reach	0	3.3	0
Downstream Reach	0	3.8	0

a. Channel is confined, and flow does not overtop banks during 100-year flow. The left and right overbanks were defined based on topographic survey of the slope break at the top of banks for the existing channel.

4.3 Natural Conditions

A natural conditions model was created for the South Tributary. This model was developed to represent the South Tributary conditions without the influence of the existing six culverts through the I-5/Lake Samish interchange to evaluate the flow conditions and determine the floodplain utilization ratio (FUR). The six culverts and the I-5 highway embankments were removed from the model mesh. Without specific historical information available about the South Tributary's exact alignment or vertical profile prior to the construction of I-5 in the early 1960s, the South Tributary's existing alignment was used for the natural conditions alignment. The vertical profile of the natural conditions channel was matched to the existing culvert invert elevations through the I-5 crossing to approximate the historical condition. The cross section for the natural conditions model used a typical surveyed cross section from the Upstream Reference Reach at BFW #2 (Figure 33). The drainage culvert near MP 290.86 remains in the natural conditions model as there is no information about a natural drainage crossing at this location, and using the same inflow condition allows a consistent comparison between modeled conditions.

The stationing for the natural conditions model cross sections is the same as for the existing conditions model (Figure 102). The FUR under natural conditions varies from 1.1 to 1.9, as shown in Table 23. The natural conditions mesh is shown in Figure 114 and the natural conditions profile is shown in Figure 115 – Figure 117. The natural conditions cross sections and 100-year velocities are shown in Figure 118 through Figure 123 and in Table 24. The natural conditions 100-year velocities ranged from 2.3 ft/sec within the Upstream Reach, 3.9 ft/sec within the Project Reach, and 4.0 ft/sec within the Downstream Reach.

Table 23: Floodplain Utilization Ratio Calculations near the I-5/Lake Samish Road Interchange

Cross Section	100-Year Top Width (feet)	2-Year Top Width (feet)	Floodplain Utilization Ratio
Sta. 11+66	5.6	4.9	1.1
Sta. 16+31	6.6	3.5	1.9
Sta. 21+42	7.2	5.1	1.4

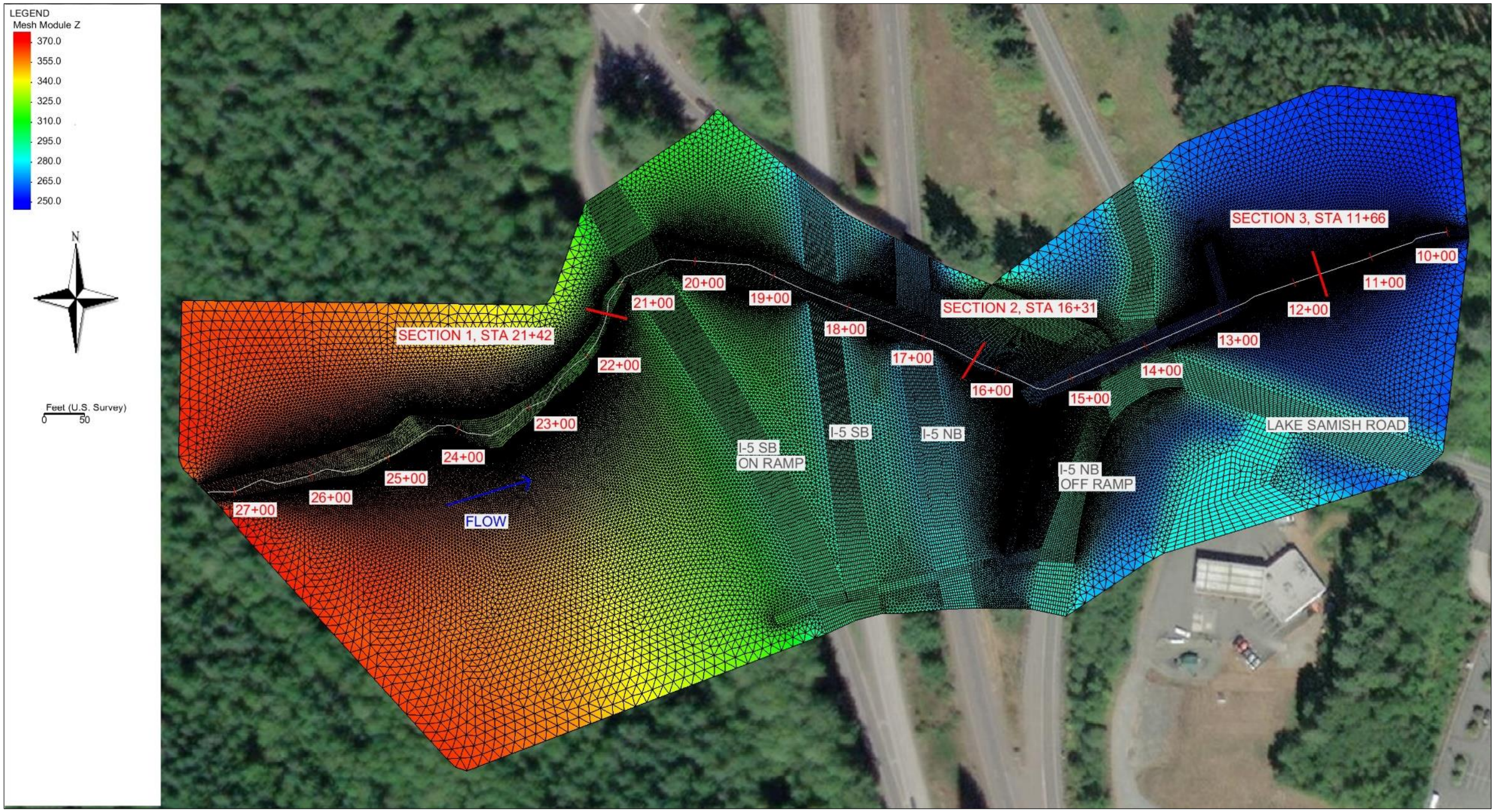


Figure 114: Plan View of Natural Conditions Model Mesh with Cross Section Locations

Figure 115: Natural Conditions Model Water Surface Profiles (overall)

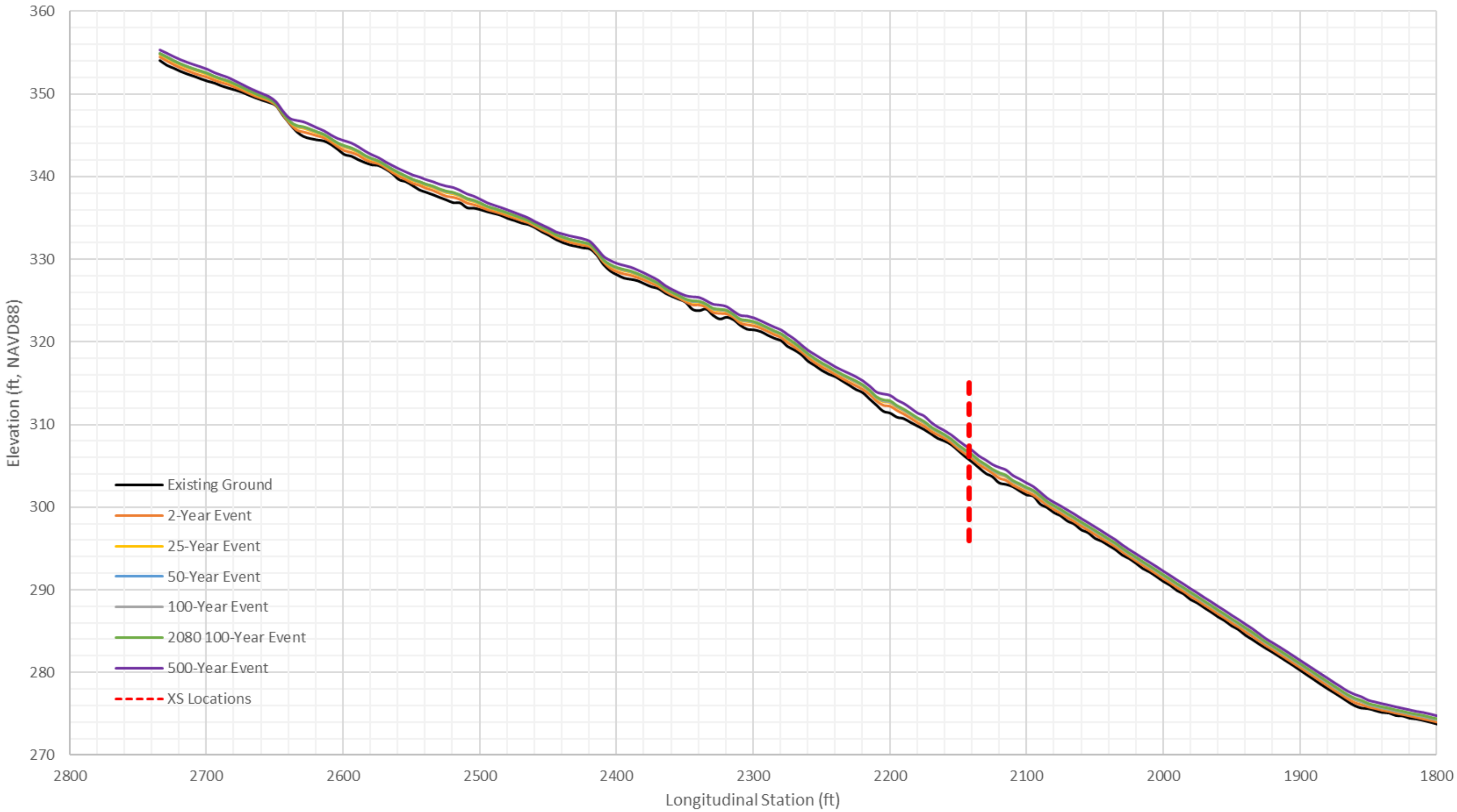


Figure 116: Natural Conditions Water Surface Profiles (upstream)

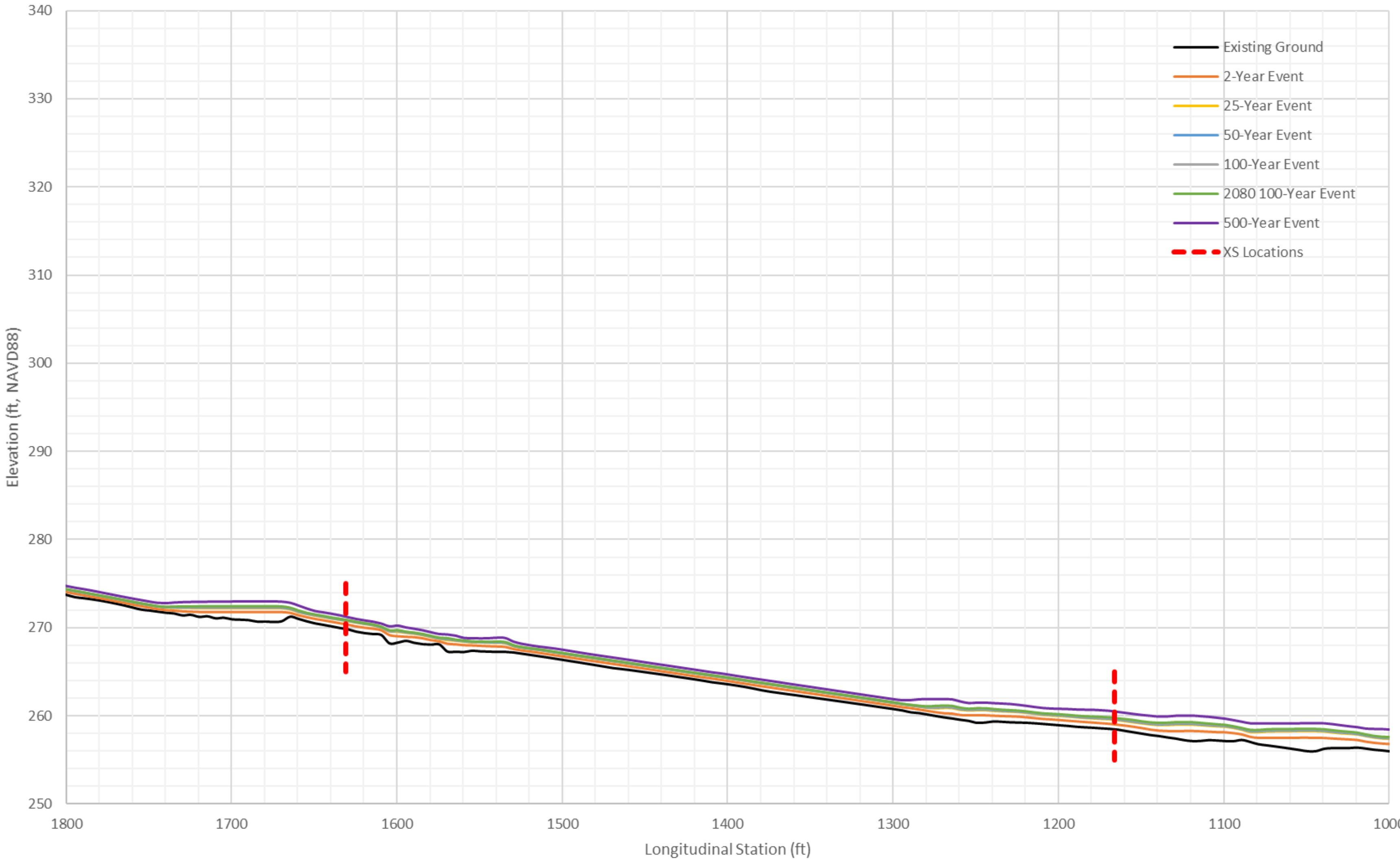


Figure 117: Natural Conditions Water Surface Profiles (downstream)

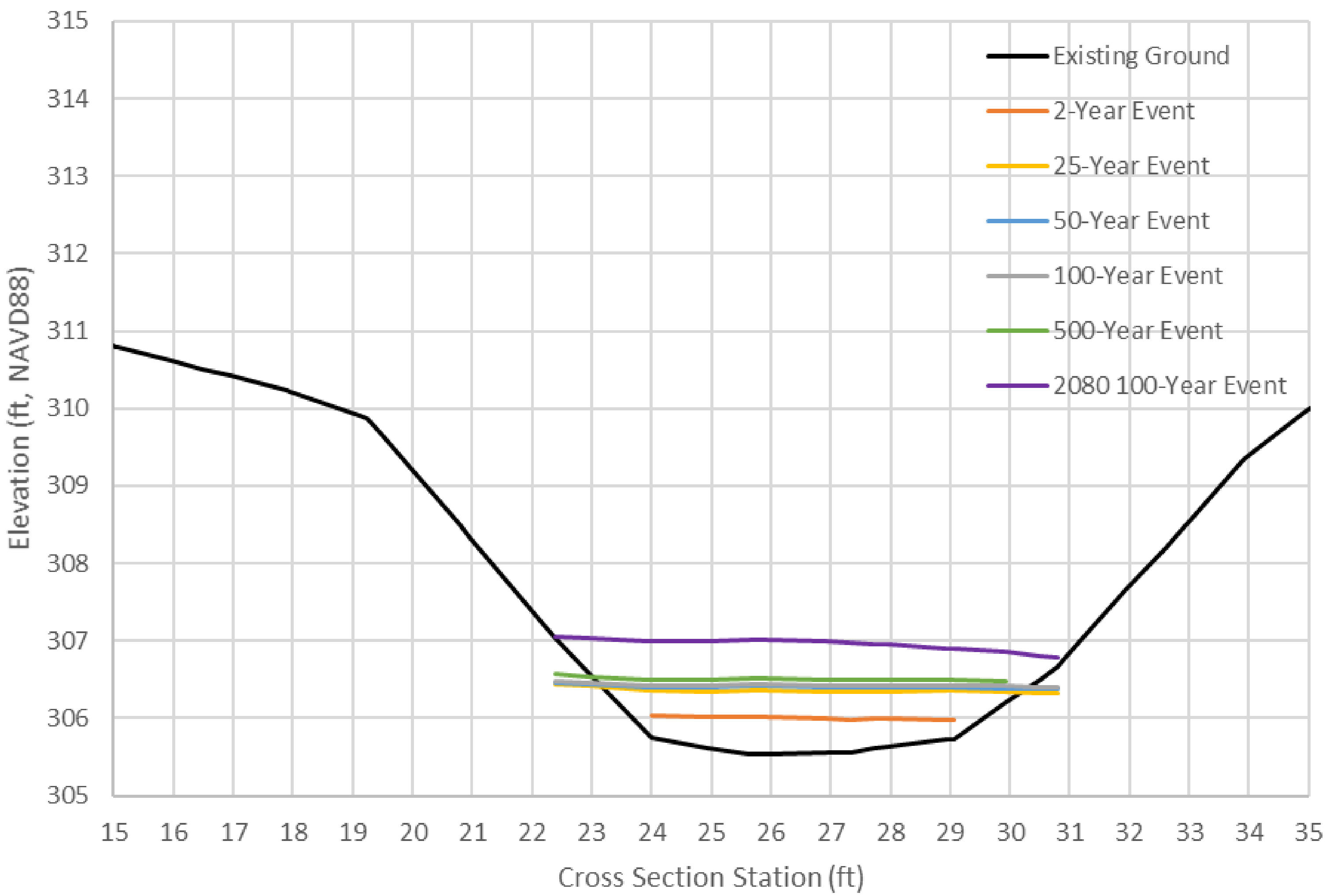


Figure 118: Typical Natural Conditions Upstream Channel Cross Section (Sta. 21+42)

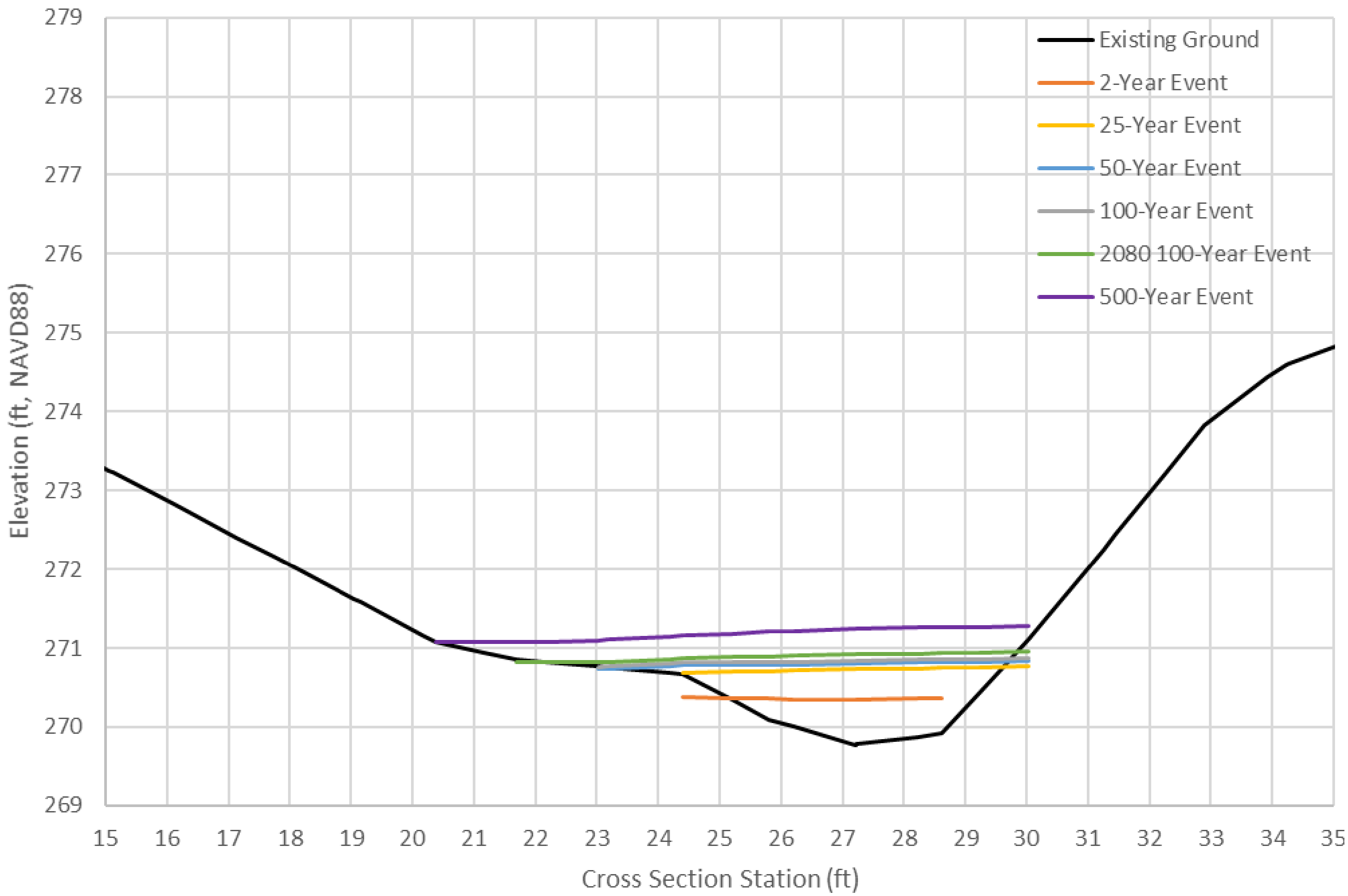


Figure 119: Typical Natural Conditions Cross Section Within Median (Sta. 16+30)

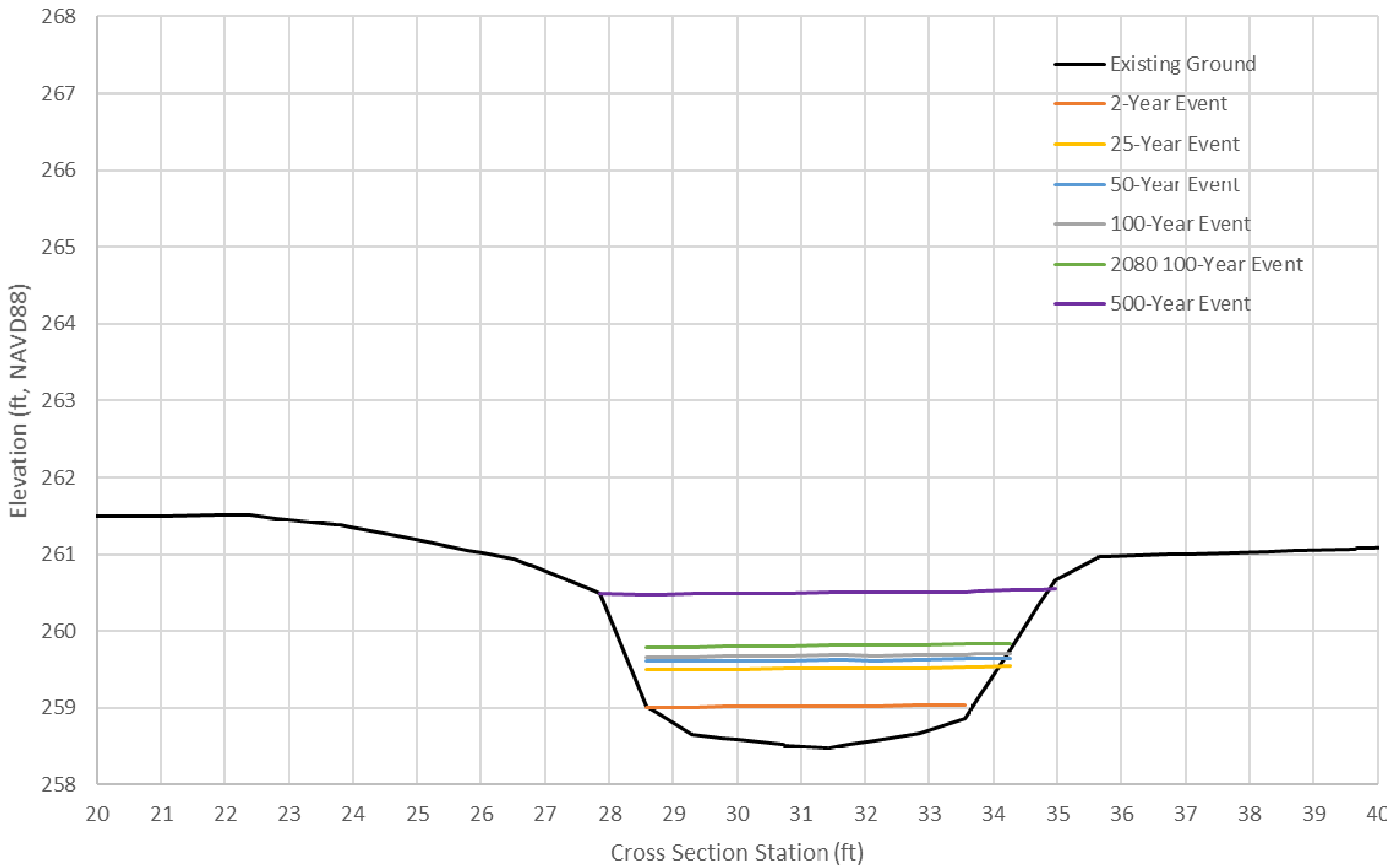


Figure 120: Typical Natural Conditions Downstream Cross Section (Sta. 1+92)

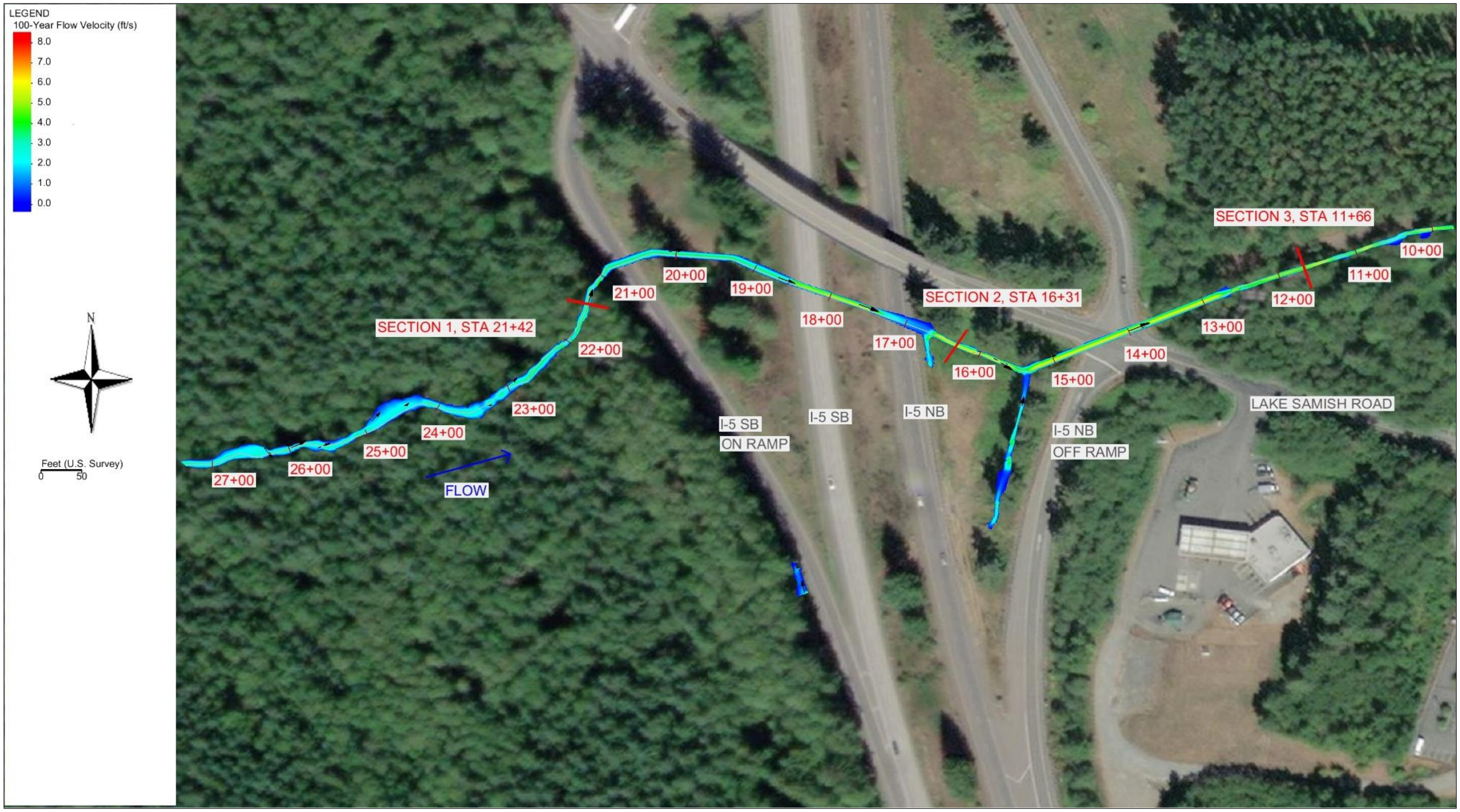


Figure 121: Natural Conditions 100-Year Velocity Map with Cross Section Locations

Figure 122: Natural Conditions 100-Year Velocity Map with Cross Section Locations (upstream)

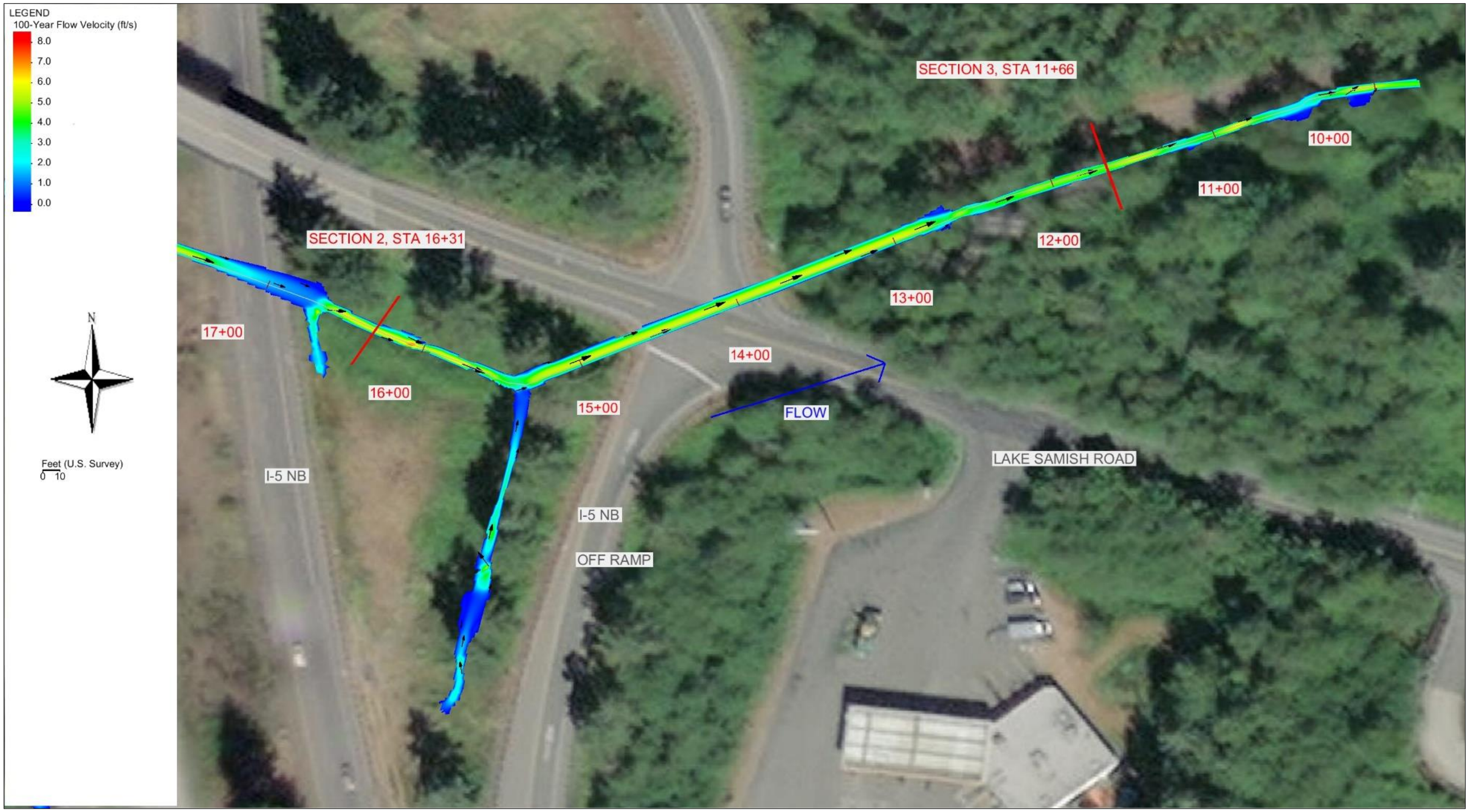


Figure 123: Natural Conditions 100-Year Velocity Map with Cross Section Locations (downstream)

Table 24: Natural Conditions Velocities Including Floodplains at Select Cross Sections

	Q100 Average Velocities (ft/s)		
	Left Overbank[a]	Main Channel	Right Overbank[a]
Upstream Reach	0	2.3	0
Project Reach (Median)	0	3.9	0
Downstream Reach	0	4.0	0

a. The left and right overbanks were defined based on topographic survey of the slope break at the top of banks at the upstream existing conditions cross section.

4.4 Channel Design

4.4.1 Floodplain Utilization Ratio

The FUR was calculated for the natural conditions model channel reaches upstream and downstream of I-5 (Table 23). The FUR was calculated at cross sections at Sta. 11+66, Sta. 16+31, and Sta. 21+42. The FUR was determined by the ratio of the width of the 100-year top width to the 2-year top width. A FUR of less than 3.0 is a confined system, and a FUR of greater than 3.0 is an unconfined system (Barnard et al. 2013). The flood-prone width (100-year top width) varies from 5.6 feet to 7.2 feet, and the 2-year top width varies from 4.9 feet to 5.1 feet. Based on the measurements utilizing the natural conditions model in the Upstream Reference Reach, the South Tributary is a confined system with an average Upstream Reach FUR of 1.4. The Downstream Reach has a FUR of 1.5, based on the average of the FUR values computed at Sta. 16+31 and Sta. 21+42 as shown in Table 23.

4.4.2 Channel Planform and Shape

The proposed channel design in the Project Reach at I-5 is presented as two separate reaches, Proposed Reach A and Proposed Reach B. The stream is designed with a cross section that approximates the Upstream Reference Reach in the steeper reaches of the proposed channel (Proposed Reach A), and a cross section that approximates the stream conditions within the Downstream Design Reach, downstream of Barleen Road, for the lower slopes of the proposed channel (Proposed Reach B). See Figure 124 for the locations of Proposed Reach A and Proposed Reach B.

Three crossing structures are also proposed at the I-5/Lake Samish Road interchange. Structure 1 is proposed under the I-5 southbound lanes and on-ramp, Structure 2 is proposed under the I-5 northbound lanes, and Structure 3 is proposed under the I-5 northbound off-ramp at Lake Samish Road (see Figure 124). The structures are discussed in more detail in later sections of this report.

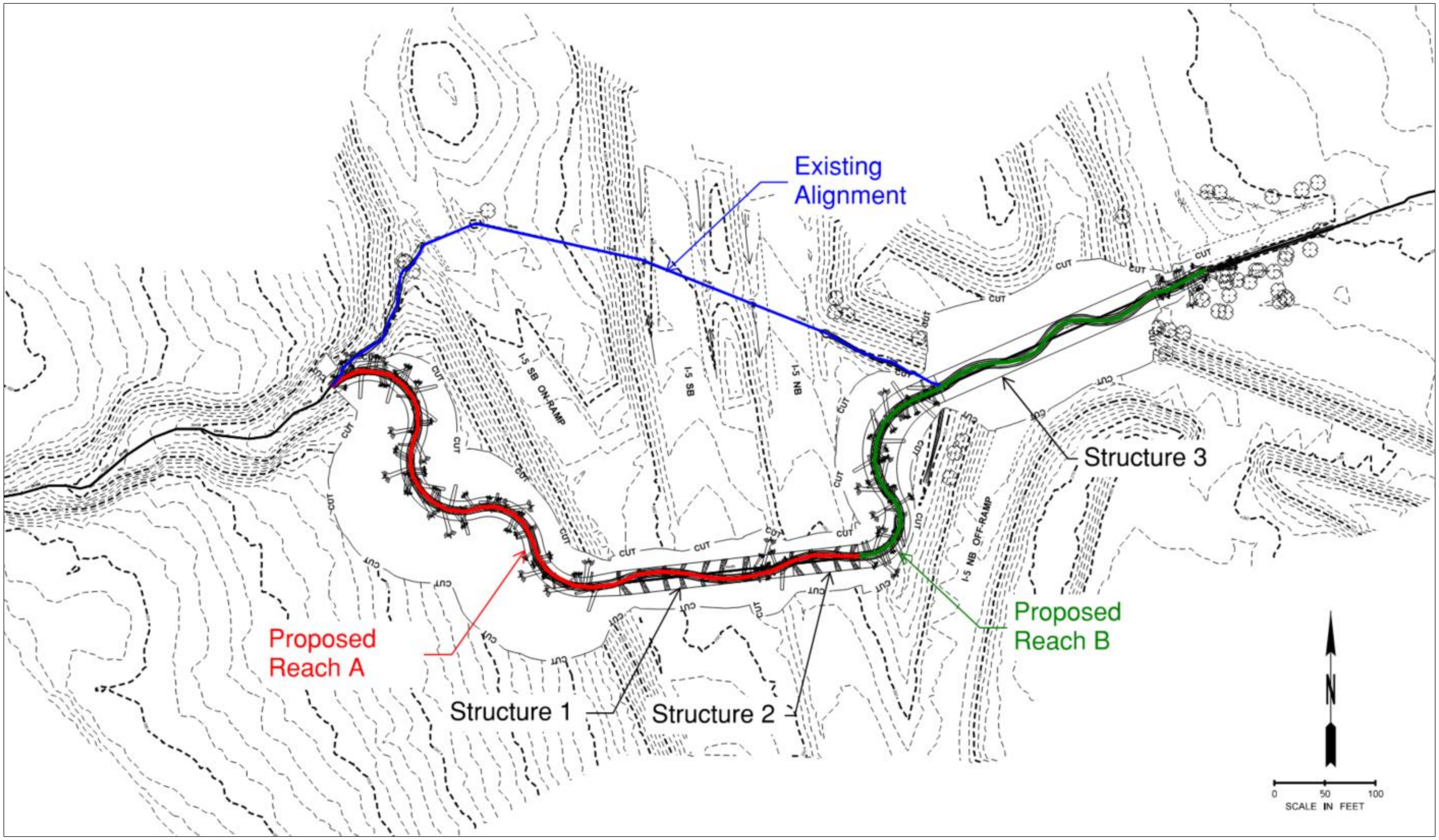


Figure 124: South Tributary Existing and Proposed Stream Channel Alignments at the I-5/Lake Samish Road Interchange

The sinuosity of the Upstream Reference Reach was measured as 1.05. This was determined by dividing the length of the stream channel by the length along the upstream reference reach valley. The meander amplitudes were measured in the Reference Reach as approximately 15 to 20 feet, and the wavelength of approximately 200 feet. The meander amplitudes were measured in accordance with the National Engineering Handbook (NEH) Part 654 Chapter 12 Figure 12-2, or the full wave amplitude (NRCS 2007). The average valley bottom width in the Reference Reach is about 22 feet based on measurements from LiDAR.

The sinuosity and meander amplitude was not calculated for the Downstream Design Reach due to its altered channel alignment along Barleen Road and the downstream agricultural field within the Friday Creek floodplain.

The NEH Part 654 Chapter 12 (NRCS 2007) provides methods for calculating meander wavelength and amplitude based on channel width and slope. Equation 12-1 from Natural Resources Conservation Service (NRCS 2007) was used to estimate meander amplitude based on top width, wavelength and sinuosity for Proposed Reach A and Proposed Reach B. The calculated meander amplitude for Proposed Reach A was 16.1 feet and for Proposed Reach B was 18.7 feet, based on a sinuosity of 1.05 and the 7.8-foot and 8.9-foot BFWs, respectively. The calculated meander amplitudes are in general agreement with the measurements from the Upstream Reference Reach.

The sinuosity of the proposed stream planform varies within the Proposed Reach A and Proposed Reach B (see Table 25). The proposed stream planform is discussed further in the following sections.

Proposed Reach A

The higher sinuosity and meander amplitude in the Proposed Reach A upstream of Structure 1 is due to the constraints in the length, slope, and width for realigning the stream to the Structure 1 inlet while maintaining a buffer from the I-5 corridor. The sinuosity and meander amplitude within Proposed Reach A within Structures 1 and 2 was developed to approximate the Upstream Reference Reach with a sinuosity of 1.02 and meander amplitudes of up to 16 feet.

The stream cross section for Proposed Reach A was developed based on the typical BFW and depth measurements of the Upstream Reference Reach, and approximating the modeled 2-year and 100-year flow depth and width for the Reference Reach. The cross-section dimensions for Proposed Reach A vary based on the longitudinal channel slope, with top widths varying from 7.2 feet to 7.6 feet. The top widths are slightly less than the average field-measured BFW of 7.8 feet in the Reference Reach. The valley slopes are shown at a 2H:1V (horizontal-to-vertical) excavation slope into the hillside in Proposed Reach A. The 2H:1V side slope is designed to reduce the effects to the established forest adjacent to the stream corridor. The typical Reference Reach cross section dimensions are shown in Table 26. The variation of the proposed cross section by longitudinal slope for Proposed Reach A is shown in Table 27. A comparison of a typical Reference Reach cross section to the proposed Reach A cross section is shown in Figure 125, and the typical Reach A cross section is shown with dimensions in Figure 126.

Proposed Reach B

The planform of Proposed Reach B was developed to realign to the inlet of Structure 3, while utilizing the width of the median area between Structures 2 and 3 for a floodplain area to the extent feasible. The sinuosity and meander amplitude of the Proposed Reach B planform within Structure 3 was developed based on the Upstream Reference Reach, but with meander amplitudes of up to about 20 feet. The Downstream Design Reach sinuosity and meander amplitude was not used for Proposed Reach B due to the modification of the planform from the adjacent agricultural land use.

The cross section for Proposed Reach B was developed based on the typical BFW and depth measurements of the Downstream Design Reach. The cross section dimensions for Proposed Reach B consist of top widths from 8.4 feet to 8.8 feet, and typical depths of 1.1 feet. The side slopes of Proposed Reach B within the median area between Structures 2 and 3 is designed with a wider riparian bench and with 3H:1V excavation slopes at the edges of the benches to promote establishment of riparian vegetation. The typical Design Reach cross section dimensions are shown in Table 26. The variation of the proposed cross section by longitudinal slope for Proposed Reach B is shown in Table 27. The typical cross section for Reach B is shown with dimensions in Figure 127.

A low-flow channel will be added in later stages of the project that connect habitat features together so that the project is not a low-flow barrier. The low-flow channel will be as directed by the Engineer in the field.

Table 25: Approximate Sinuosity, Meander Amplitude, and Meander Length of Proposed Reach A and Proposed Reach B Compared to the Upstream Reference Reach

Reach	Approximate Sinuosity	Approximate Meander Amplitude (feet)	Approximate Meander Length (feet)	Average Slope (%)
Upstream Reference Reach	1.05	15–20	200	8.1
Proposed Reach A – Upstream	1.25	19–50	230	8.1
Proposed Reach A – Structures 1 and 2	1.02	14–16	170	6.3–4.1
Proposed Reach B – Downstream of Structure 2	1.19	44	190	3.2–1.7
Proposed Reach B – Structure 3	1.04	12–17	155	1.7
Downstream Design Reach (below Barleen Road)		NA	NA	2.5

Table 26: Upstream Reference Reach and Downstream Design Reach Typical Dimensions

Reach Number and Type	Slope (%)	Typical Bottom Width (feet)	Typical Bankfull Depth (feet)	Bankfull Width (feet)
Upstream Reference Reach	8.1	4.0	1.0	5.7–9.6
Downstream Design Reach	2.5	5.4	1.1	7.4–9.3

Table 27: Proposed Typical Cross-Section Dimensions for Proposed Reach A and Proposed Reach B by Longitudinal Slope

Reach Number and Type	Longitudinal Slope (%)	Channel Bottom Width (feet)	Channel Bottom Slope	Channel Side Slopes	Bank Height (feet)	Total Channel Depth (feet)	Top Width (feet)
Proposed Reach A – Upstream	8.1	4.0	10H:1V	2H:1V	0.8	1.0	7.2
Proposed Reach A – Upstream	7.9	4.0	10H:1V	2H:1V	0.8	1.0	7.2
Proposed Reach A – Structure 1	6.3	4.5	10H:1V	2H:1V	0.8	1.0	7.6
Proposed Reach A – Between Structure 1 and 2	5.1	4.5	10H:1V	2H:1V	0.8	1.0	7.6
Proposed Reach A – Structure 2	4.1	4.5	10H:1V	2H:1V	0.8	1.0	7.6
Proposed Reach B – Downstream of Structure 2	3.2	5.0	10H:1V	2H:1V	0.9	1.1	8.4
Proposed Reach B – Downstream of Structure 2	2.6	5.0	10H:1V	2H:1V	0.9	1.1	8.4
Proposed Reach B – Downstream of Structure 2	2.1	5.0	10H:1V	2H:1V	0.9	1.1	8.4
Proposed Reach B – Structure 3	1.7	5.5	10H:1V	2H:1V	0.9	1.1	8.8

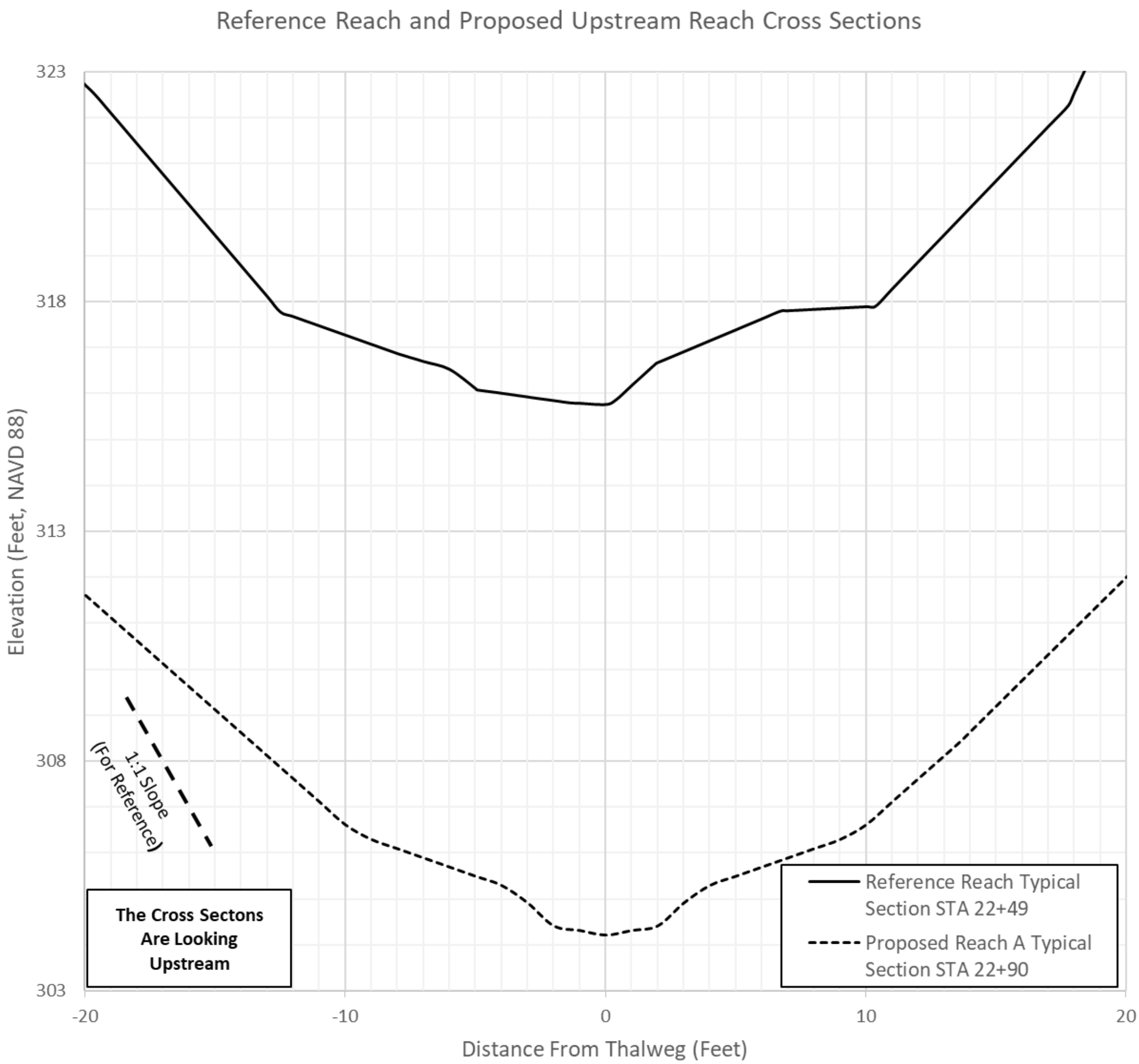


Figure 125: Comparison of the Proposed Reach A Cross Section to the Typical Upstream Reference Reach Cross Section

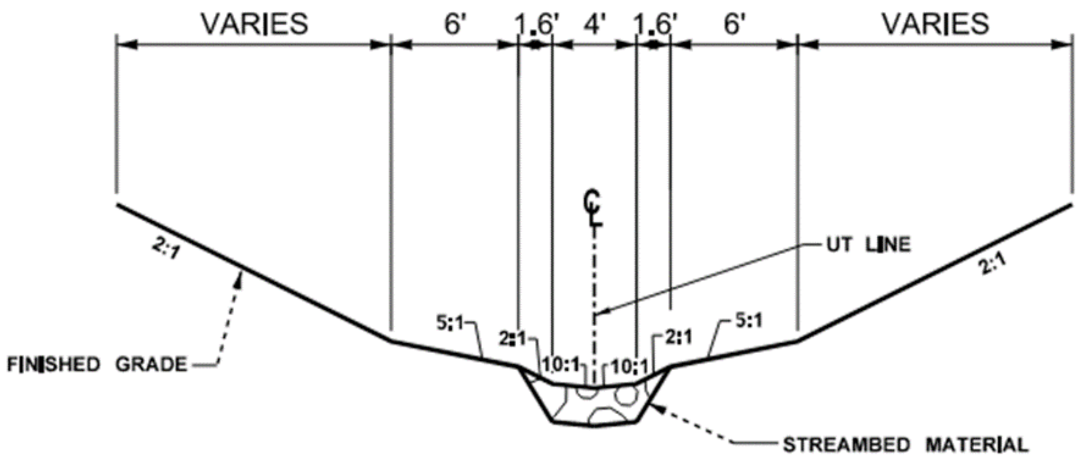


Figure 126: Typical Cross Section for Reach A

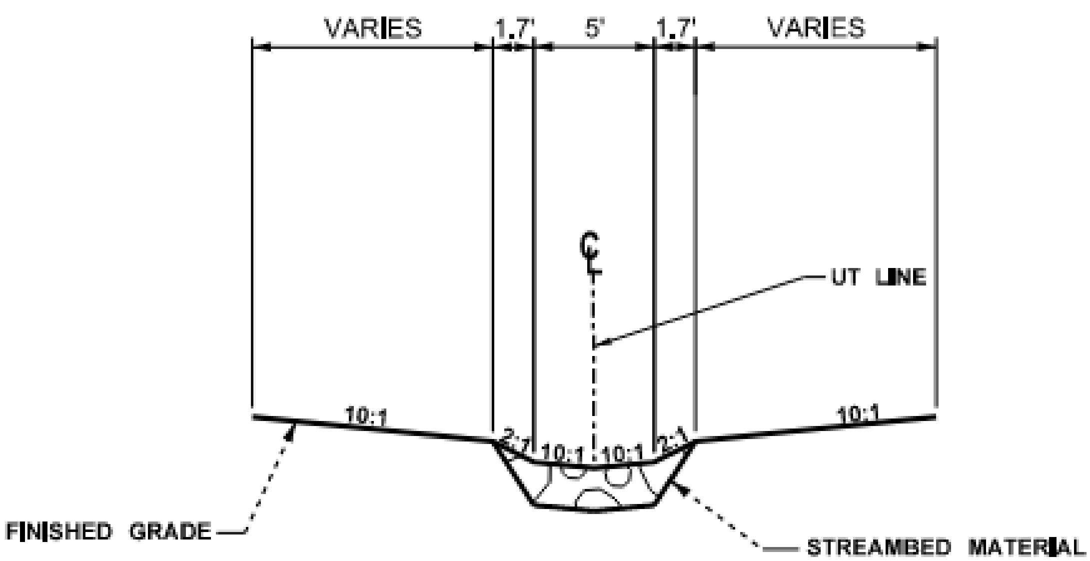


Figure 127: Typical Cross Section for Reach B

4.4.3 Channel Alignment

The proposed channel alignment was developed as a result of alternative evaluations to determine a preferred approach for achieving fish passage using stream simulation slopes. Project alternatives were evaluated and presented by Otak to WSDOT and project partners from April through June of 2021. See Figure 128 for the example alternatives considered for the stream realignment. Upon review of the various alignments, evaluations by Otak, and comments from the co-managers, WSDOT selected the South Tributary realignment in this report (Alternative 1) as the preferred alternative. Alternative 1 was then developed further. It was necessary to move the grading tie-in point farther upstream, similar to Alternative 4, to maintain a buffer between I-5 and the stream corridor.

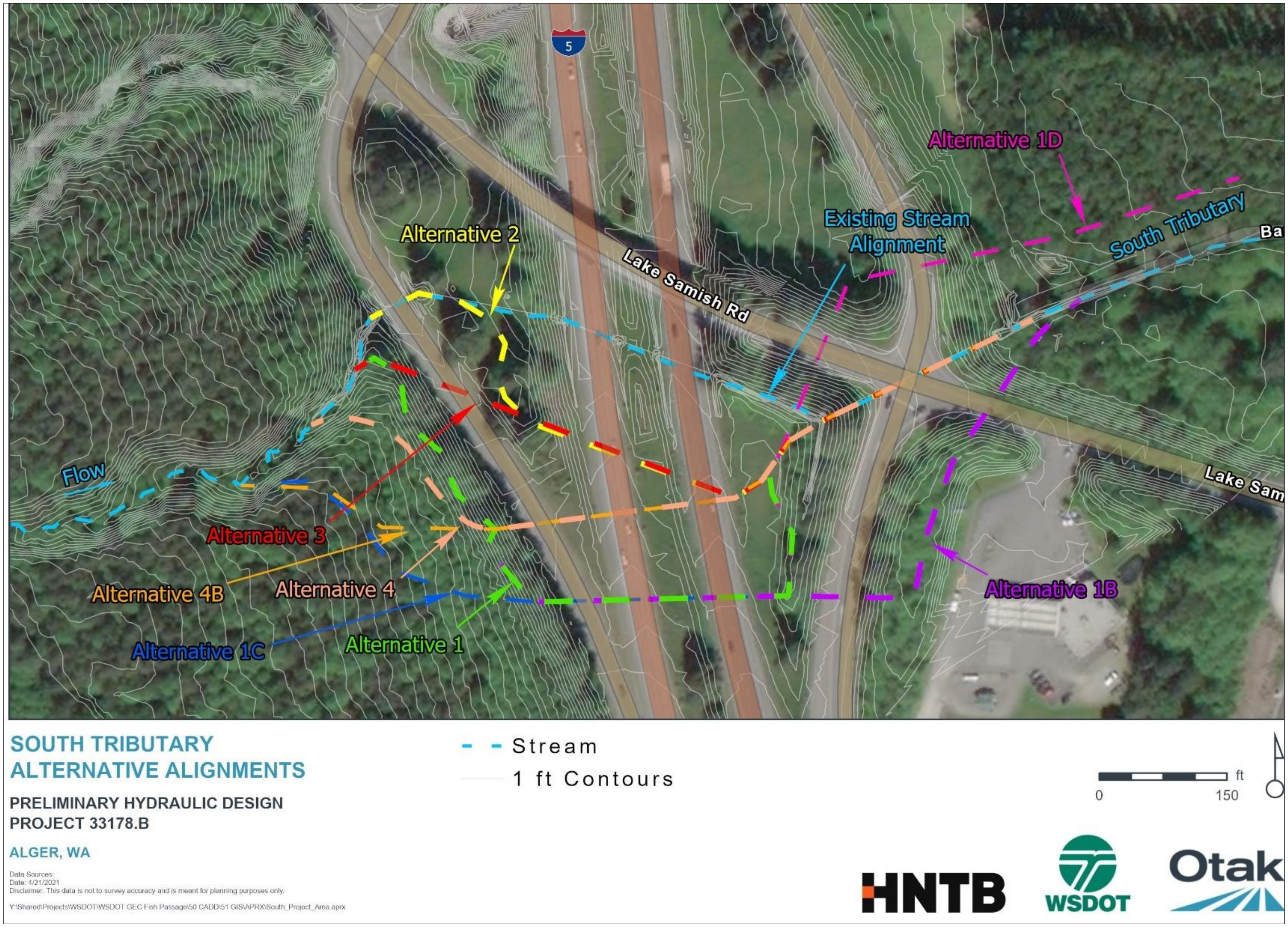


Figure 128: South Tributary Summary of Alternative Alignments

The preferred alternative realigns the South Tributary approximately 300 feet to the south of the existing Culvert 995236 to cross under I-5 where the roadway grade is higher. The reasons to reroute the stream to the south to the higher roadway grade include: 1) to reduce the slope of the stream at the I-5 crossings to meet stream simulation criteria, and 2) to allow for the necessary clearance within the structure for freeboard and maintenance.

The total length of the Proposed Reach A is about 673 feet. The length of the channel grading upstream of Structure 1 is approximately 434 feet. Structure 1 is approximately 131 feet in length. The channel grading between Structure 1 and Structure 2 is approximately 42 feet in length. Structure 2 is about 66 feet in length.

The total length of the Proposed Reach B is about 520 feet. Proposed Reach B consists of an open channel reach approximately 230 feet long and Structure 3 under the I-5 off-ramp and Lake Samish Road, which is approximately 232 feet long. An additional channel grading length of about 58 feet is proposed downstream of Structure 3, which is also part of Proposed Reach B.

This proposed alignment increases the channel length by approximately 225 feet from the existing condition (through the I-5/Lake Samish Interchange). This alignment requires grading/excavating approximately 400 feet of new stream channel upstream of I-5 and approximately 280 feet of new open channel grading downstream of I-5. See Appendix E for the Preliminary Stream Plan, Profile, and Sections.

The proposed alignment upstream I-5 goes through a vegetated hillslope that contains mature trees. The specific locations of those trees were not surveyed for the analysis and were not incorporated into design of the channel alignment. As the project progresses into the Final Hydraulic Design (FHD) phase, an analysis of tree impact will be performed based on the location of the mature trees and the excavation limits of the proposed alignment. Based on the analysis, minor adjustments to the proposed stream alignment will be made to minimize loss of mature trees, where possible, while preserving the proposed stream profile and maintaining a stream planform similar to that of the current proposed design. At the completion of final design, the comanagers will attend a site visit to observe the excavation extents and trees that will be removed.

The existing culverts and stream channel within the I-5/Lake Samish Road interchange will remain in place to provide stormwater drainage from on-site runoff and I-5. This includes the existing portion of stream channel between the I-5 northbound lanes and the I-5 northbound off-ramp. This section of existing channel will be graded out to ensure stormwater conveyance from the existing set of culverts to the proposed channel at the upstream end of Structure 3. The open channel will be graded and potentially filled in a manner to ensure that fish stranding will not occur when there is stormwater flow in the existing culverts. This grading will be further examined during the FHD phase.

4.4.4 Channel Gradient

Proposed Reach A

The average slope in the Upstream Reference Reach (8.1 percent) was used for the Proposed Reach A stream profile upstream of Structure 1. The Proposed Reach A stream gradient meets the WCDG stream simulation guidelines by not exceeding the upstream channel slope ratio of 1.25. The profile was developed to transition from the 8.1 percent slope upstream to the approximately 1.7 percent slope downstream by creating transition slopes that do not exceed a slope ratio of 1.25. The profile for the proposed stream alignment is shown in Figure 129.

The realigned stream within Proposed Reach A will have a maximum slope of approximately 8.1 percent upstream of I-5 in the newly regraded channel, and slopes of about 6.3 percent and 4.1 percent for Structures 1 and 2 under the I-5 southbound and northbound lanes, respectively. This reduction in slope allows for the crossing structures to be designed using WCDG stream simulation methodology and improves the gradient for upstream fish passage. The Structure 1 and Structure 2 slopes remain below the 8.1 percent slope of the Reference Reach.

The proposed channel morphology in Proposed Reach A is based on Montgomery and Buffington (1993) stream classification system (Figure 130). Step-pools are proposed for the channel slopes and structures greater than 3 percent slope, and plane-bed and pool riffle systems are proposed for the lower sloped channels and structures. Stable LWM will be placed throughout the open channel grading. These in-channel features will provide roughness and will help to maintain the channel grade along this reach, with the intent of the stream naturally developing a step-pool morphology through Proposed Reach A. Due to the steep slopes from the transition from the hillside to the valley floor, there is a potential of vertical adjustments of the realigned South Tributary profile if the stream channel is not adequately roughened with large and small wood placement to emulate the relative stability of the Reference Reach. The long-term degradation and aggradation potential of the realigned stream is discussed in Section 8.2.

Structure 1 and Structure 2 are proposed with step-pool morphology following measurements from the step-pools observed in the Reference Reach (see Section 2.8.1 and Table 6). The proposed step-pools are discussed in Section 5.1.4.

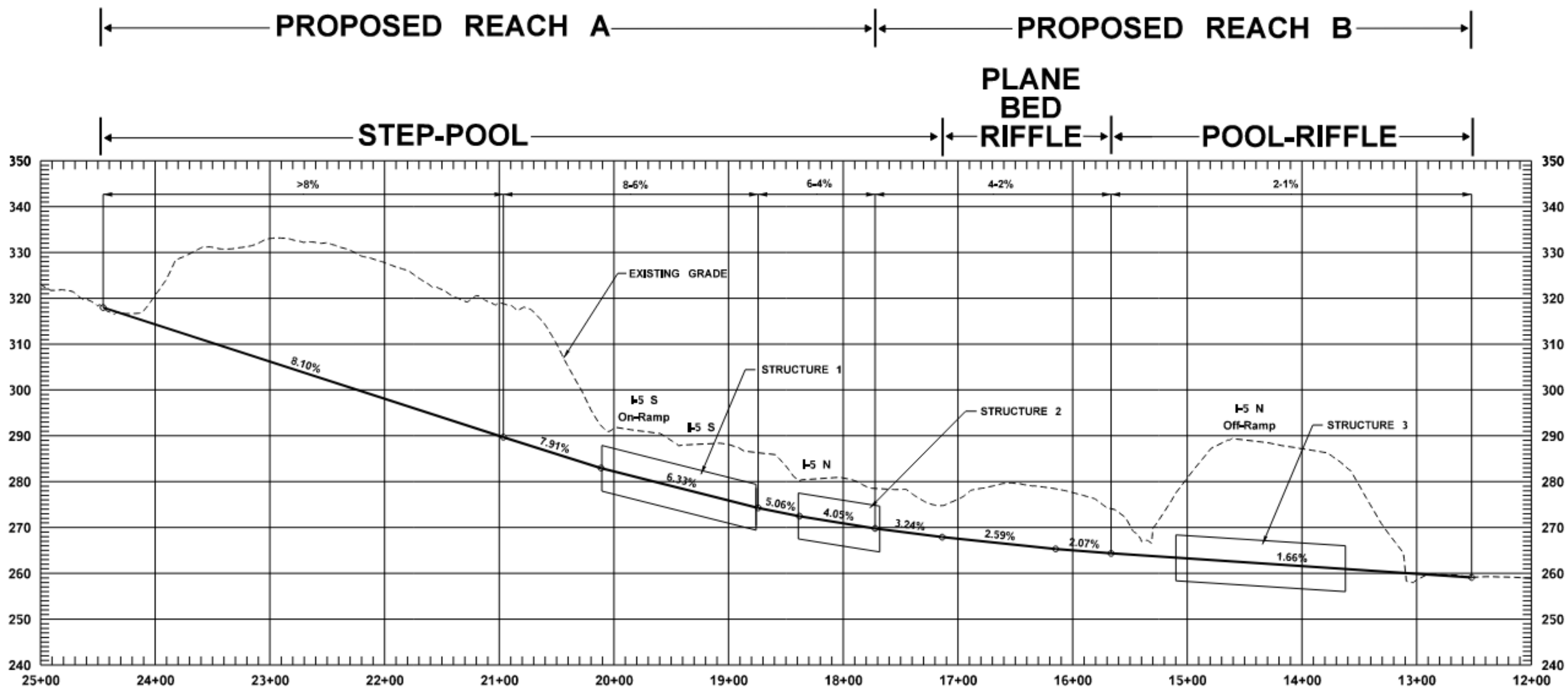


Figure 129: Proposed Stream Profile with Slopes and Typical Stream Morphologies

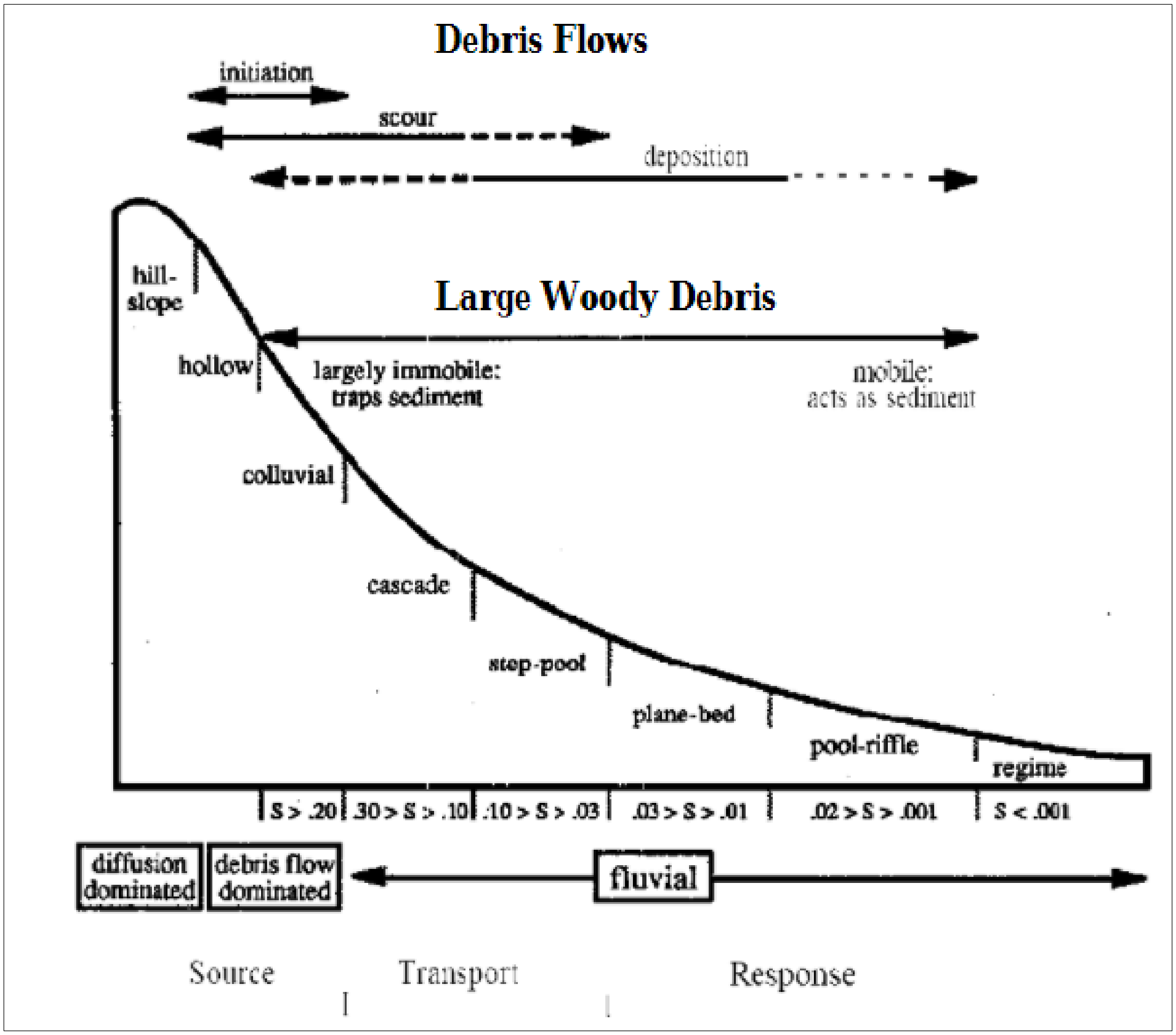


Figure 130: Channel Types and Associated Slopes (taken from Montgomery and Buffington 1993)

Proposed Reach B

The Downstream Design Reach has an average gradient of 2.5 percent. The channel gradient of Proposed Reach B has a slope of about 3.2 percent with several transition slopes down to a slope of about 1.7 percent at Structure 3. The transition slopes from 3.2 percent to 1.7 percent were selected to not exceed a slope ratio of 1.25 relative to the immediately upstream slope. The slope transitions are designed to provide gradual changes in slope to reduce the amount of potential sediment deposition anticipated at any given change in slope.

The proposed channel morphology in Proposed Reach B is based on Montgomery and Buffington (1993) stream classification system (Figure 130). For the 3.2 percent slope within Proposed Reach B, step-pool morphology is proposed using stable LWM to provide roughness and to help to maintain the channel grade along this reach. A plane-bed morphology is typical between slopes of 1 percent and 3 percent, and pool-riffle morphology is typical between slopes of 1 percent and 2 percent (Figure 130). For the Proposed Reach B slopes from 2.6 percent to about 1.7 percent, stable LWM is proposed within the open channel to encourage a forced pool-riffle morphology. For Structure 3, meander bars consisting of stable cobbles, gravels, and buried slash are proposed at the slope of about 1.7 percent. The meander bars within Structure 3 are discussed further in Section 5.1.5.

4.5 Design Methodology

The proposed fish-passage design was developed using the 2013 WCDG (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2022a). Using the guidance in these two documents, the stream simulation design method was determined to be the most appropriate for the crossings. As the proposed design includes a significant channel realignment, which will interrupt some natural stream alluvial fan processes such as channel migration, plan form, and sediment transport patterns, the stream simulation as described in the 2013 WCDG cannot be fully followed. However, stream simulation design along proposed channel alignment is followed wherever possible. Due to site the complexity and design constraints at the site, this design methodology was followed and agreed upon with the comanagers. The minimum hydraulic opening was increased beyond the minimum from the stream simulation design method, as described further in Section 4.6. The stream simulation criteria that the design meets include the following:

- Proposed Reach A (slopes greater than 4 percent):
    - BFW of less than 15 feet (Upstream Reference Reach BFW average is 7.8 feet)
    - Proposed Reach A slopes are equal to or less than the Upstream Reference Reach slope of 8.1 percent
    - Proposed Reach A slopes are also less than a ratio of 1.25 relative to the immediately upstream slope
    - An average FUR of 1.4 (confined conditions)
    - Adequate flood clearance at crossings under I-5
    - Infrastructure not at a high risk due to channel migration or channel degradation

- Proposed Reach B (slopes less than 4 percent):
  - BFW of less than 15 feet (Downstream Design Reach BFW average of 8.9 feet)
  - Proposed Reach B slopes are also less than a ratio of 1.25 relative to the immediately upstream slope
  - A downstream FUR of 1.1 (confined conditions)
  - Adequate flood clearance at crossings under Lake Samish Road Interchange
  - Infrastructure not at a high risk due to channel migration or channel degradation

4.6 Future Conditions – Proposed Minimum Hydraulic Openings

The hydraulic opening is defined as the width perpendicular to the stream beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic opening assumes vertical walls at the edge of the minimum hydraulic opening width unless otherwise specified.

The starting point for the design of all WSDOT structures is Equation 3.2 of the WCDG, rounded up to the nearest whole foot (Barnard et al. 2013). The minimum hydraulic opening using Equation 3.2 based on BFW is 12 feet for Proposed Reach A and 13 feet for Proposed Reach B. The proposed minimum hydraulic opening was increased to 24 feet for Proposed Reach A and to 28 feet for Proposed Reach B, as discussed in Sections 4.6.1 and 4.6.2.

4.6.1 Proposed Reach A

The minimum hydraulic opening is proposed as 24 feet for Structure 1 and Structure 2. The 24 feet minimum hydraulic opening is based on maintaining the approximate stream planform from the Upstream Reference Reach through Structures 1 and 2. The sinuosity and meander amplitudes from the Reference Reach and Structures 1 and 2 are discussed in Section 4.4.2 and shown in Table 25.

The proposed conditions model topography, cross-section locations, and stationing are shown in Figure 131 and Figure 132. The stream planform, as well as the step-pools, were modeled in Structures 1 and 2. The step-pools were represented in the model using the step-pool profiles as well as the proposed grading shown on the preliminary plans. The step-pool dimensions are discussed in Section 5.1.4.

The WSEs, flows depths, flow velocities, and bed shear are compared upstream of the structures, and within the structures, in Table 28 through Table 31. The Structure 1 results provide flow depths and velocities similar to those in the upstream and downstream channels. Velocities are slightly higher within the structures due to the lower roughness without in-channel wood. The step-pools add roughness and decrease the slope between steps, reducing flow velocities within Structures 1 and 2. The velocities within the structures remain relatively low, given the steep slopes, with flow velocities of less than 2 ft/sec for a 2-year peak flow, and about 3 ft/sec for a 100-year peak flow. The velocities decrease downstream of the structures due to the lower slope. The 100-year peak flow velocities are shown in Figure 133 - Figure 135, and the 2080 100-year peak flow velocities are shown in Figure 145 - Figure 146. See Appendix C for the SRH-2D model results.

Upstream of the proposed grading connection at Sta. 24+60, the existing channel geometry is based on the LiDAR topographic data, and the modeled existing cross section has a lower depth, is wider, and has lower modeled velocities than the existing channel within the survey limits. The existing channel within the survey limits at Sta. 21+42 has an average 100-year channel velocity of 2.6 ft/sec, with a maximum velocity of 3.8 ft/sec. The modeled velocity within Proposed Reach A upstream of Structure 1 at Station 20+20, has an average channel velocity of 3.0 ft/sec, with a maximum velocity of 4.0 ft/sec. The changes in modeled velocity are likely a result of the higher Manning's n roughness value assumed for the upstream existing channel based on the variability of the existing channel. Variability from large wood and buried slash under proposed conditions will approximate the upstream channel variability. 100-year peak flow channel and floodplain velocities are shown in Table 34. 2080 100-year peak flow channel and floodplain velocities are shown in Table 35.

The flow depths in Table 28 through Table 31 are average depths across the channel and, therefore, are lower than the flow depth at the thalweg (the maximum flow depth). Maximum channel flow depths for Structure 1 are 0.5 foot for the 2-year peak flow and 1.0 foot for the 100-year peak flow. Maximum channel flow depths for Structure 2 are 0.6 foot for the 2-year peak flow and 1.1 feet for the 100-year peak flow. WSE profiles for the proposed channel are shown in Figure 136 - Figure 138. Typical cross sections are shown with flow depths for Proposed Reach A in Figure 139 - Figure 142.

The modeled 2-year peak flow depth of 0.5 foot at the channel thalweg is less than the average measured bankfull depth upstream due to the incised channel. More than a 100-year peak flow is likely required to reach bankfull depth within the upstream channel. The modeled 2-year flow depths are consistent with the observed flow depths within the Upstream Reference Reach. The channel shape is expected to adjust over time and is discussed in Section 8.1 and Section 8.2.

4.6.2 Proposed Reach B

The minimum hydraulic opening is proposed as 28 feet for Structure 3. The Downstream Design Reach appeared to be impacted by adjacent land use and had insufficient length (80 linear feet) to accurately determine the stream plan form or adequately provide indication of key geomorphic features that could be used for the design of Structure 3. The 28-foot minimum hydraulic opening is based on providing a proposed plan form through Structure 3 that approximates the Upstream Reference Reach but has a small increase in meander amplitude based on the larger BFW and lower slope of the Downstream Design Reach. The sinuosity and meander amplitudes for Structure 3 are discussed in Section 4.4.2 and shown in Table 25.

The hydraulic results upstream and downstream of Structure 3, and inside of Structure 3, are summarized in Table 32 and Table 33. Flow velocities within Structure 3 are higher than in the upstream Proposed Reach B channel due to the lower roughness without in-channel wood. The meander bars provide roughness, and velocities are lower in Structure 3 than in the

Downstream Reach. Flow velocities within Structure 3 are less than 2 ft/sec for the 2-year peak flow, and about 3.4 ft/sec for the 100-year peak flow.

Average flow depths across the channel are shown in Table 32 and Table 33. The maximum channel flow depths are 0.6 foot for the 2-year peak flow, and 1.3 feet for the 100-year peak flow. Typical cross sections are shown with flow depths for Proposed Reach B in Figure 144 - Figure 145.

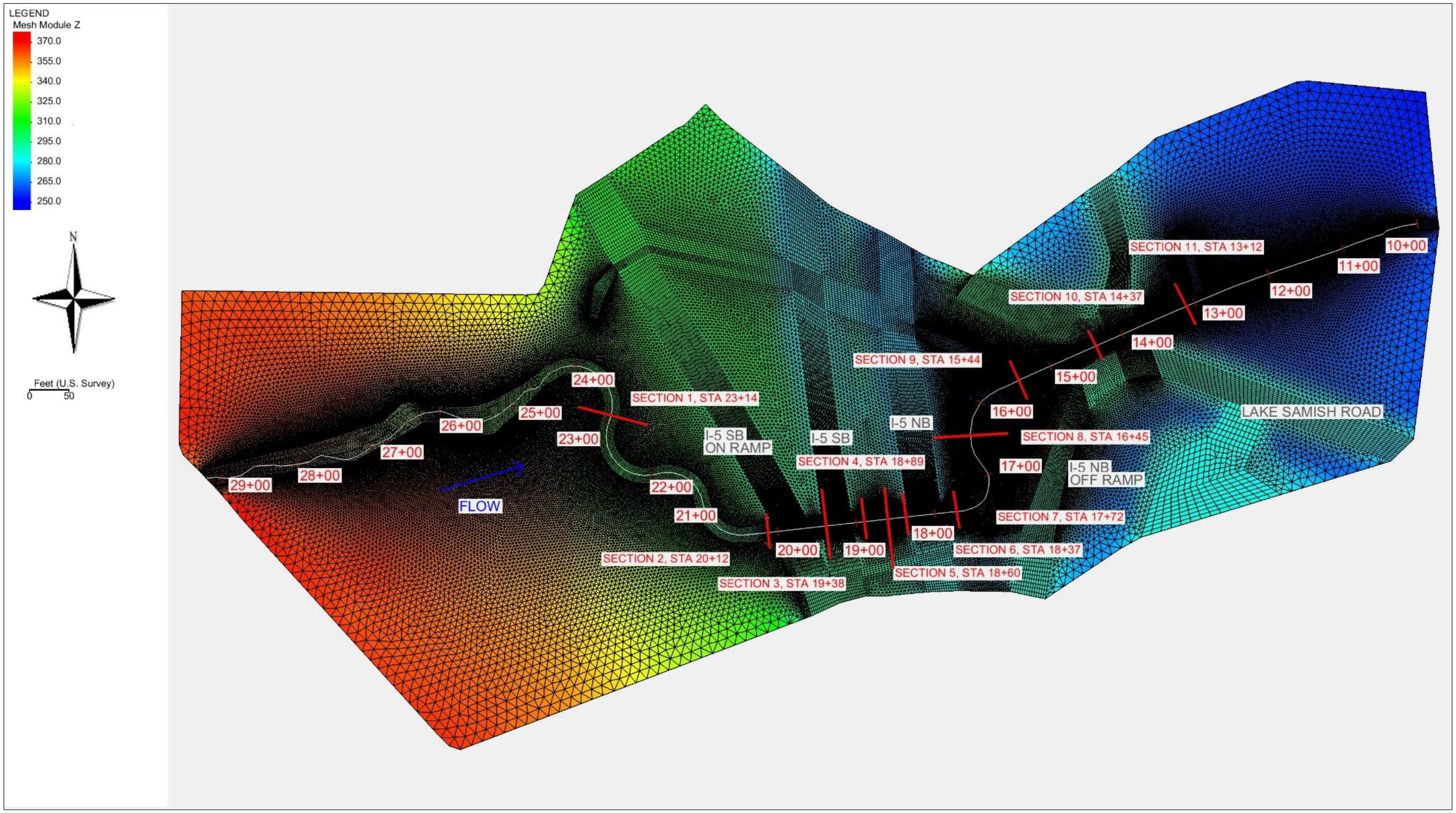


Figure 131: South Tributary Locations of Cross Sections Used for Proposed Conditions Results Reporting

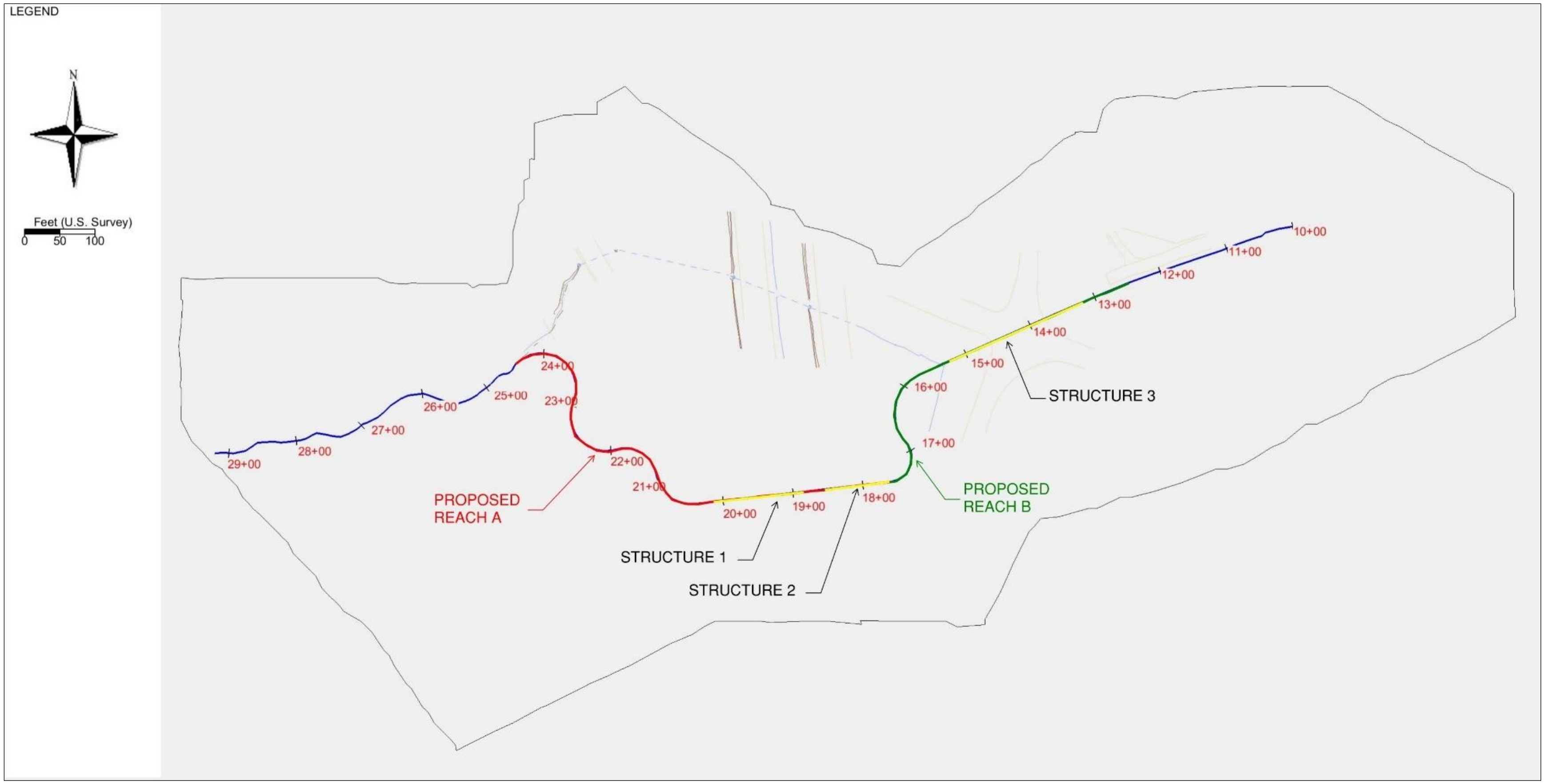


Figure 132: Longitudinal Profile Stationing for Proposed Conditions

Table 28: Average Main Channel Hydraulic Results for Proposed Conditions Upstream (Sta. 20+12) and Downstream (Sta. 18+89) of Structure 1

Event (Years)	WSE (feet)		Depth (feet)		Velocity (ft/sec)		Shear (lb/ft^2)	
	US	*DS*	*US*	*DS*	*US*	*DS*	*US*	*DS*
2	284.6	274.6	0.3	0.3	1.8	1.6	1.3	0.9
100	284.6	274.6	0.6	0.7	3.0	3.1	3.0	2.1
500	285.1	275.1	1.1	1.1	4.9	4.4	4.8	3.4
2080 Predicted 100	284.7	274.7	0.7	0.8	3.4	3.4	3.0	2.3

Table 29: Average Main Channel Hydraulic Results for Proposed Conditions Within Structure 1 (Sta. 19+38)

Event (Years)	WSE (feet)	Depth (feet)	Velocity (ft/sec)	Shear (lb/ft^2)
2	279.3	0.3	2.0	0.9
100	279.3	0.6	3.4	1.7
500	279.7	1.1	5.1	3.1
2080 Predicted 100	279.4	0.7	3.7	1.9

Table 30: Average Main Channel Hydraulic Results for Proposed Conditions Upstream (Sta. 18+37) and Downstream (Sta. 17+72) of Structure 2

Event (Years)	WSE (feet)		Depth (feet)		Velocity (ft/sec)		Shear (lb/ft^2)	
	US	*DS*	*US*	*DS*	*US*	*DS*	*US*	*DS*
2	274.6	270.7	0.3	0.4	1.6	1.2	0.9	0.4
100	274.6	270.7	0.7	0.8	3.1	2.2	2.1	0.9
500	275.1	271.1	1.1	1.3	4.4	3.4	3.4	1.7
2080 Predicted 100	274.7	270.7	0.8	0.9	3.4	2.4	2.3	1.0

Table 31: Average Main Channel Hydraulic Results for Proposed Conditions Within Structure 2 (Sta. 18+08)

Event (Years)	WSE (feet)	Depth (feet)	Velocity (ft/sec)	Shear (lb/ft^2)
2	272.1	0.4	1.9	0.6
100	272.1	0.7	3.0	1.2
500	272.6	1.2	4.7	2.2
2080 Predicted 100	272.2	0.8	3.4	1.3

Table 32: Average Main Channel Hydraulic Results for Proposed Conditions Upstream (Sta. 15+44) and Downstream (Sta. 13+12) of Structure 3

Event (Years)	WSE (feet)		Depth (feet)		Velocity (ft/sec)		Shear (lb/ft^2)	
	US	*DS*	*US*	*DS*	*US*	*DS*	*US*	*DS*
2	265.3	261.1	0.4	0.3	1.7	2.3	0.7	0.3
100	265.3	261.1	0.8	0.8	2.5	3.5	1.1	0.5
500	265.7	262.0	1.3	1.6	3.3	2.9	1.7	0.3
2080 Predicted 100	265.4	261.2	0.9	0.9	2.7	3.5	1.2	0.5

Table 33: Average Main Channel Hydraulic Results for Proposed Conditions Within Structure 3 (Sta. 14+37)

Event (Years)	WSE (feet)	Depth (feet)	Velocity (ft/sec)	Shear (lb/ft^2)
2	263.3	0.4	1.9	0.4
100	263.3	0.8	3.4	0.7
500	263.7	1.2	4.4	1.1
2080 Predicted 100	263.4	0.9	3.6	0.8

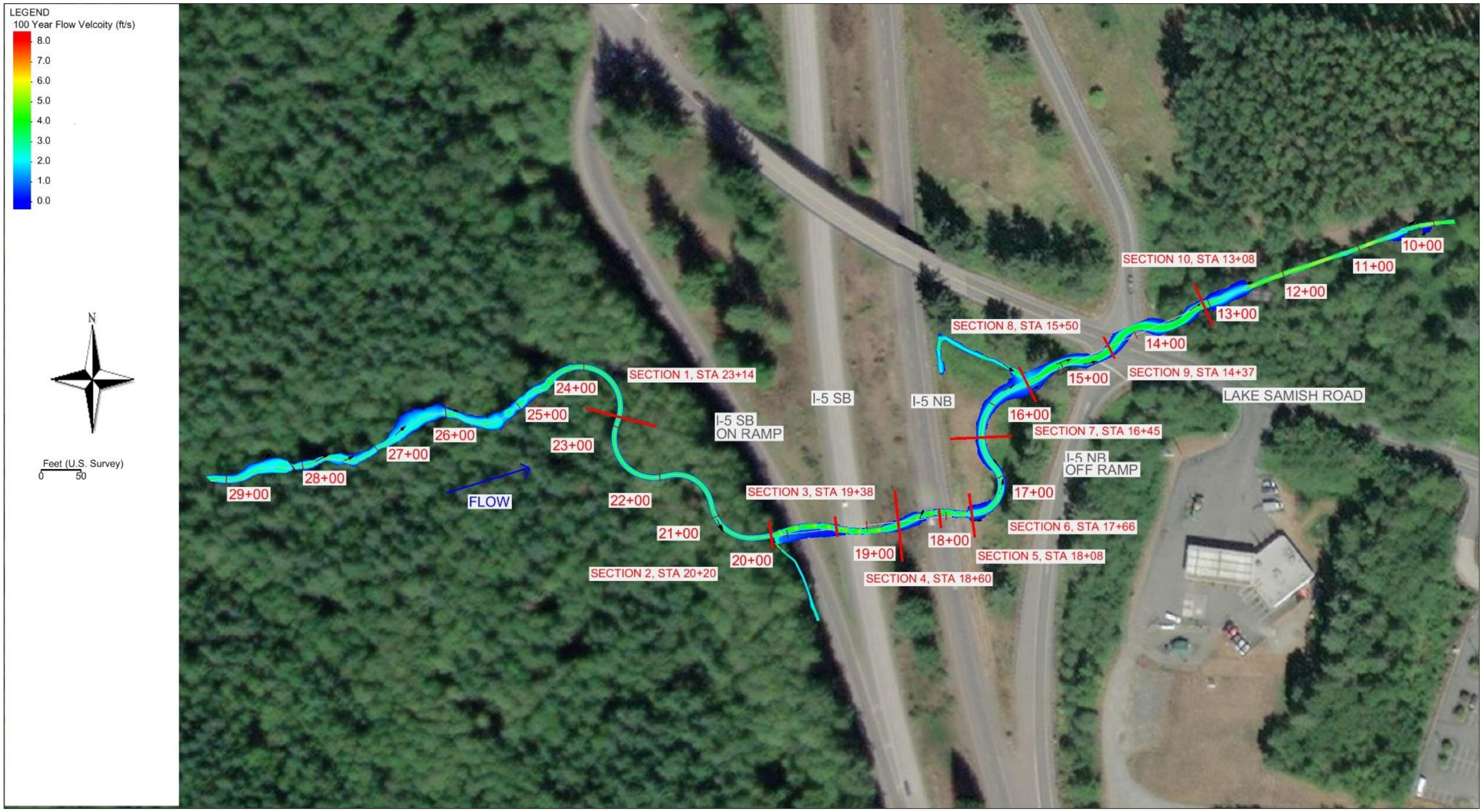


Figure 133: Proposed Conditions 100-Year Velocity Map (overall)

Figure 134: Proposed Conditions 100-Year Velocity Map (upstream)

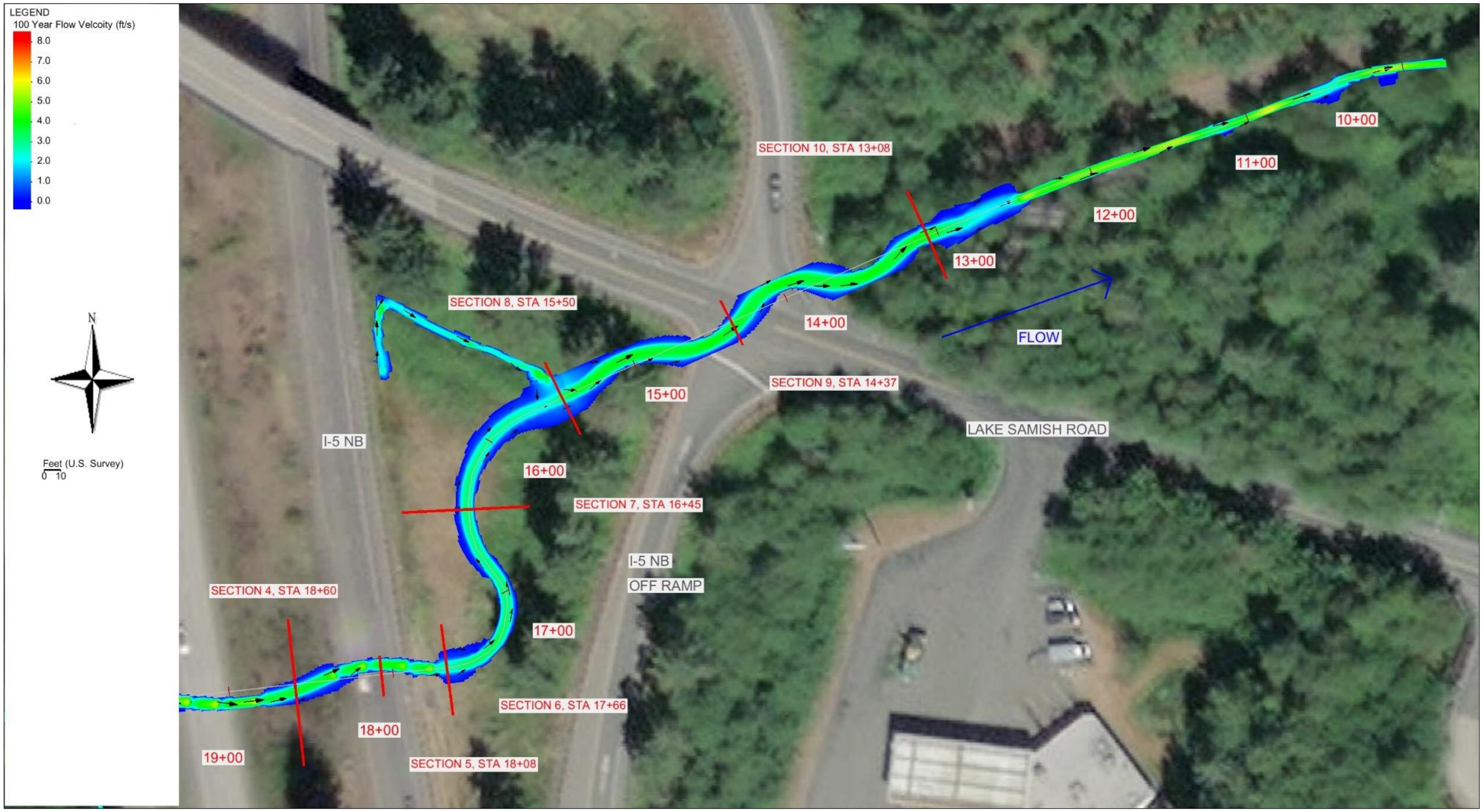


Figure 135: Proposed Conditions 100-Year Velocity Map (downstream)

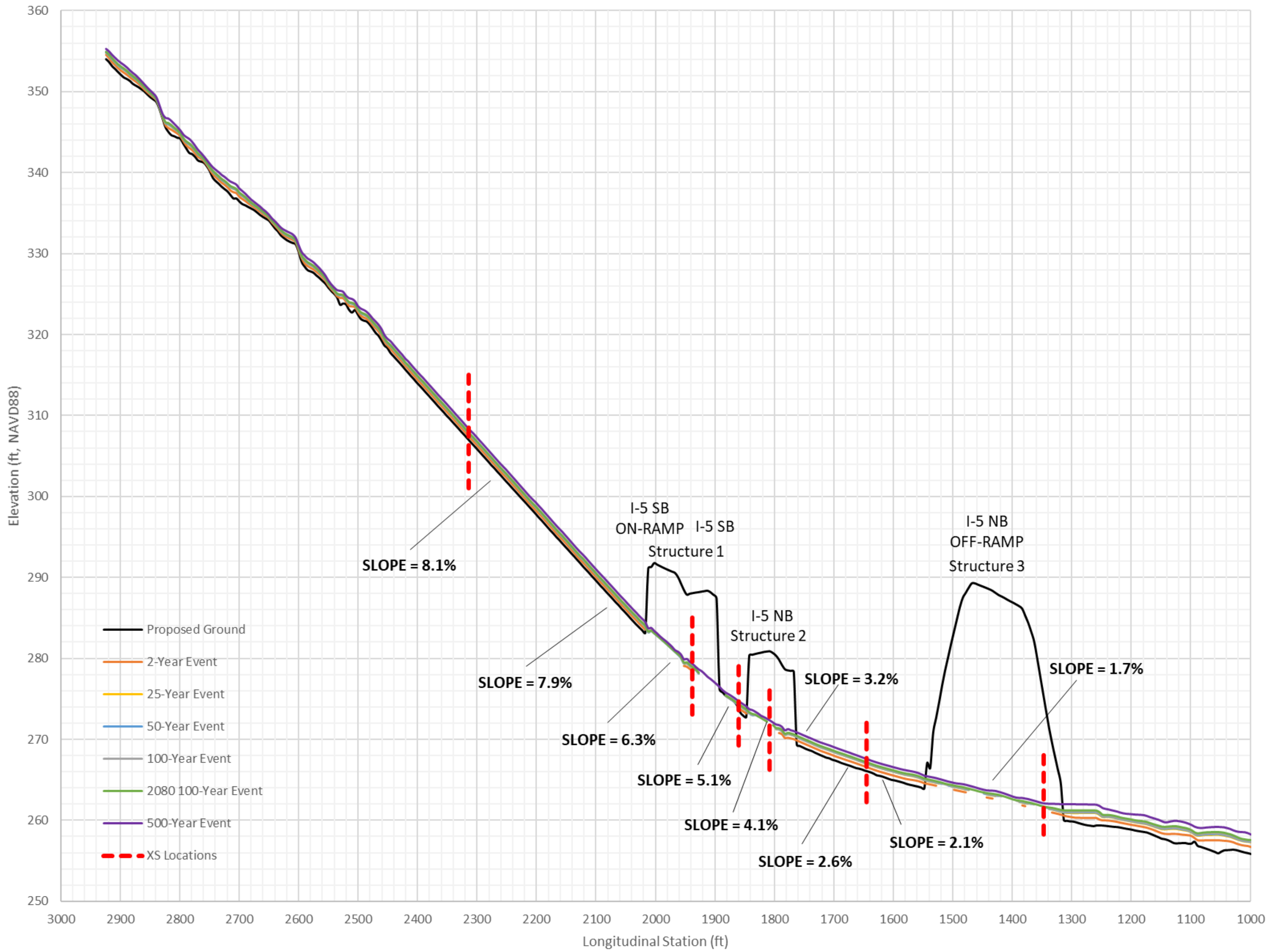


Figure 136: Proposed Conditions Water Surface Profiles (overall)

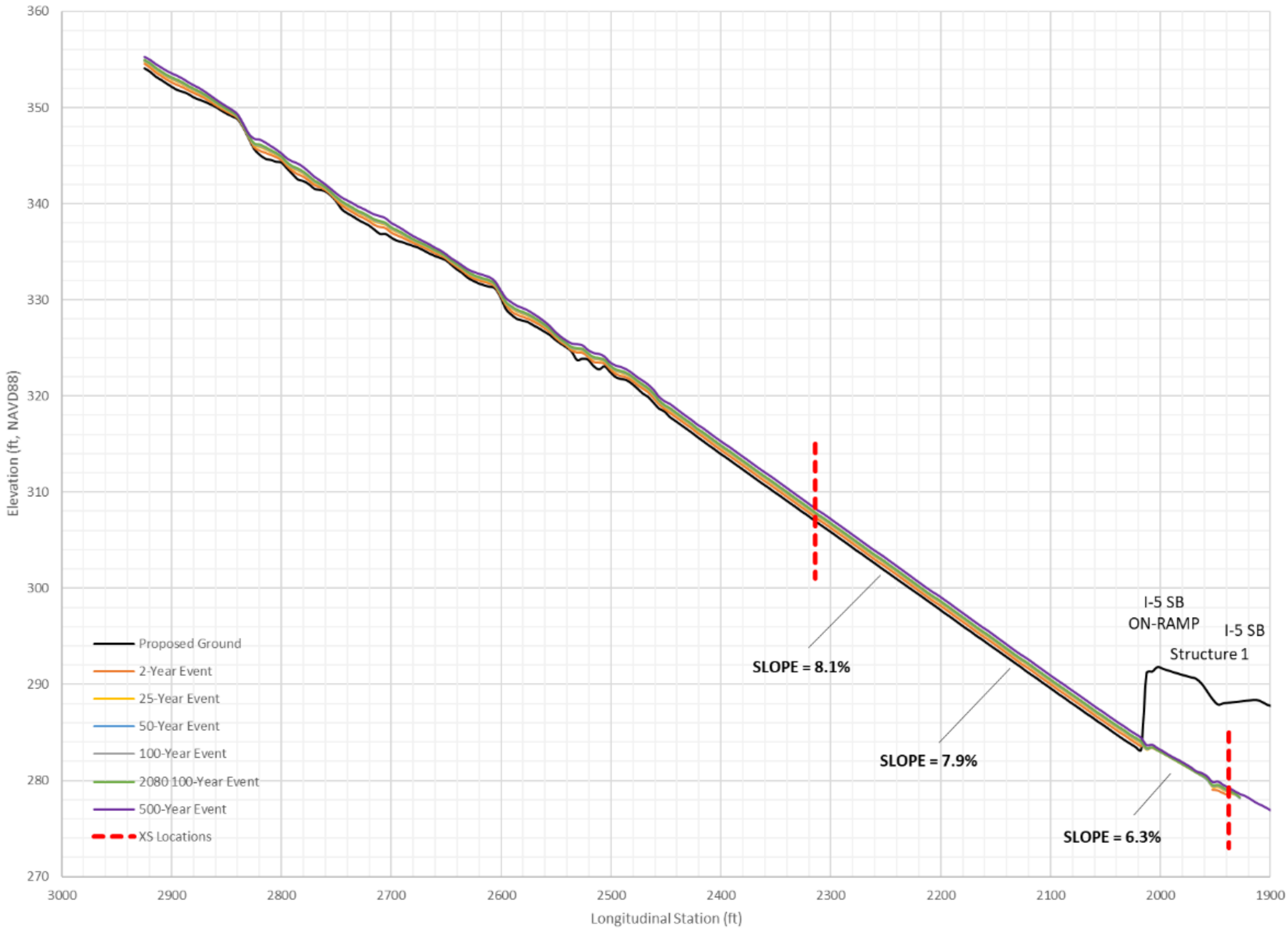


Figure 137: Proposed Conditions Water Surface Profiles (upstream)

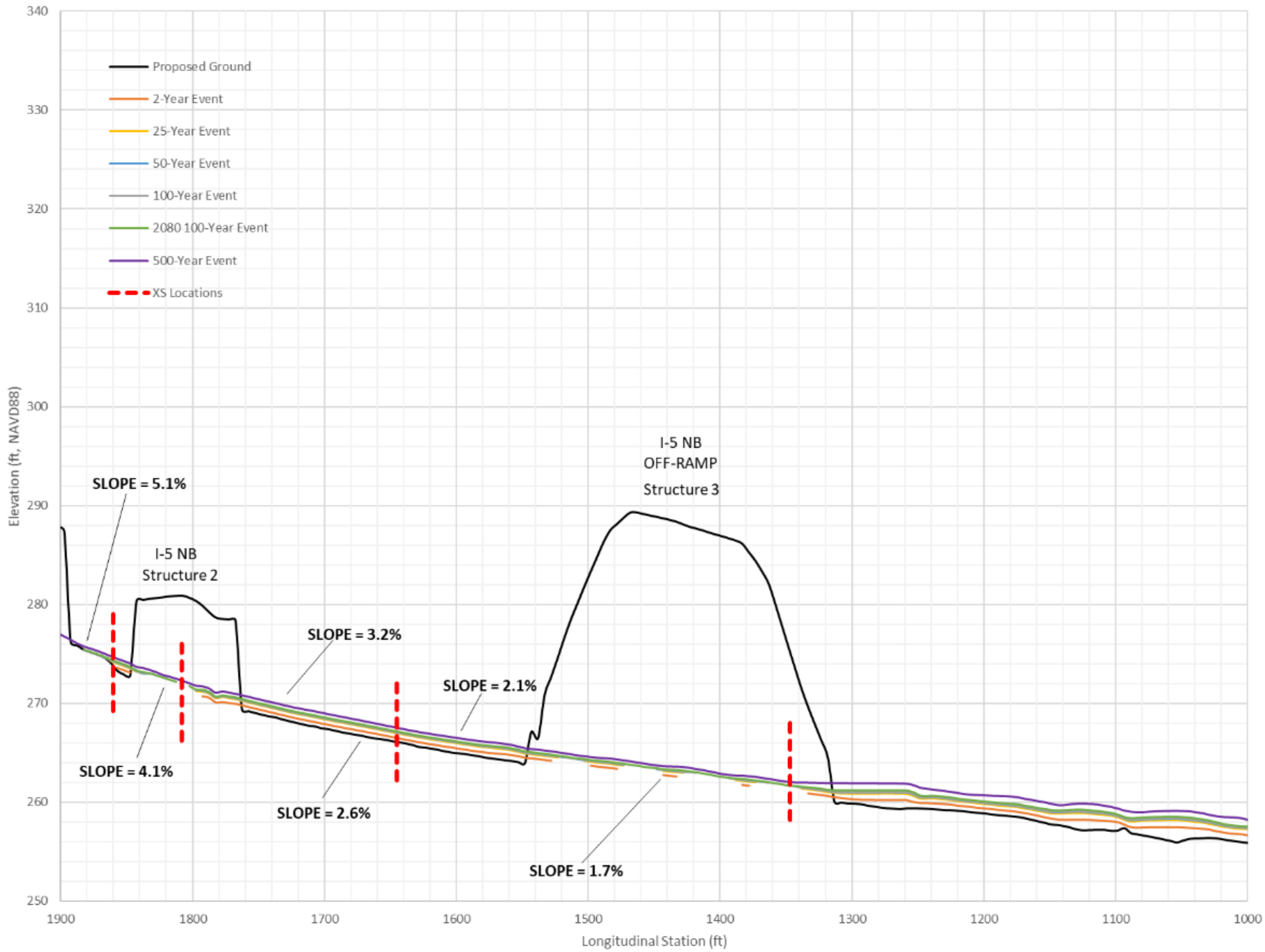


Figure 138: Proposed Conditions Water Surface Profiles (downstream)

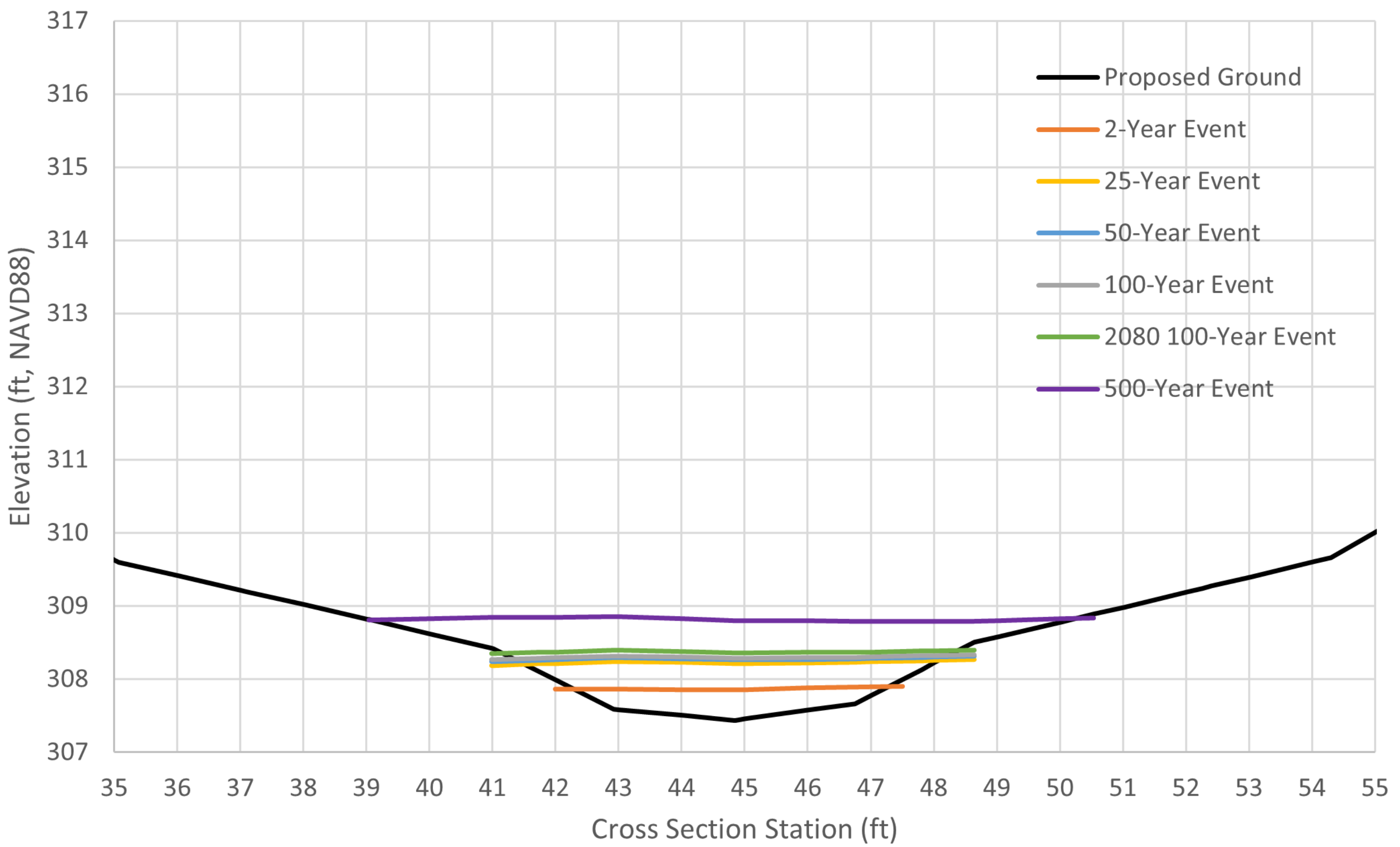


Figure 139: Typical Section in Proposed Reach A, Upstream Channel (Sta. 23+14)

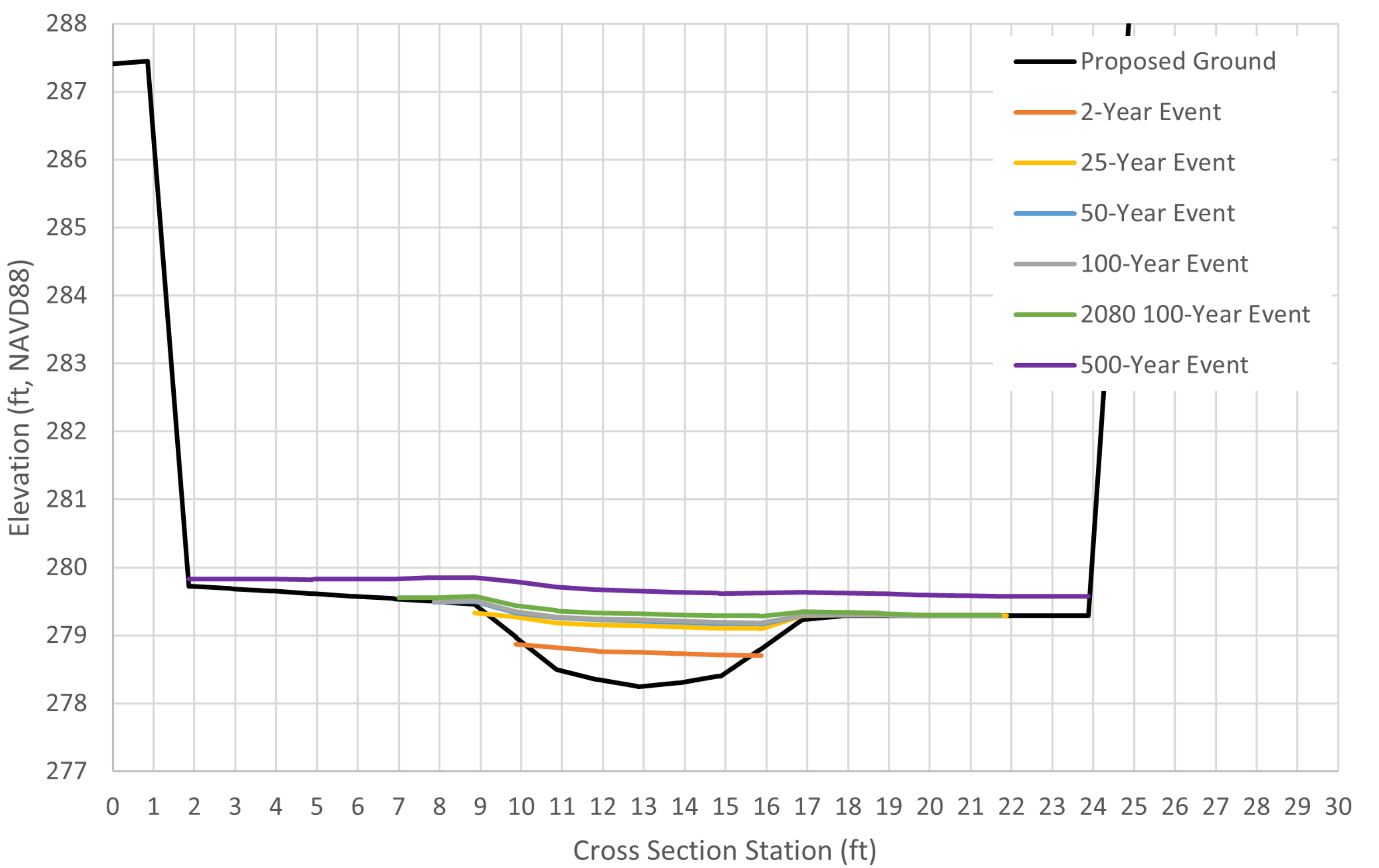


Figure 140: Typical Section through Proposed Structure 1 (Sta. 19+38)

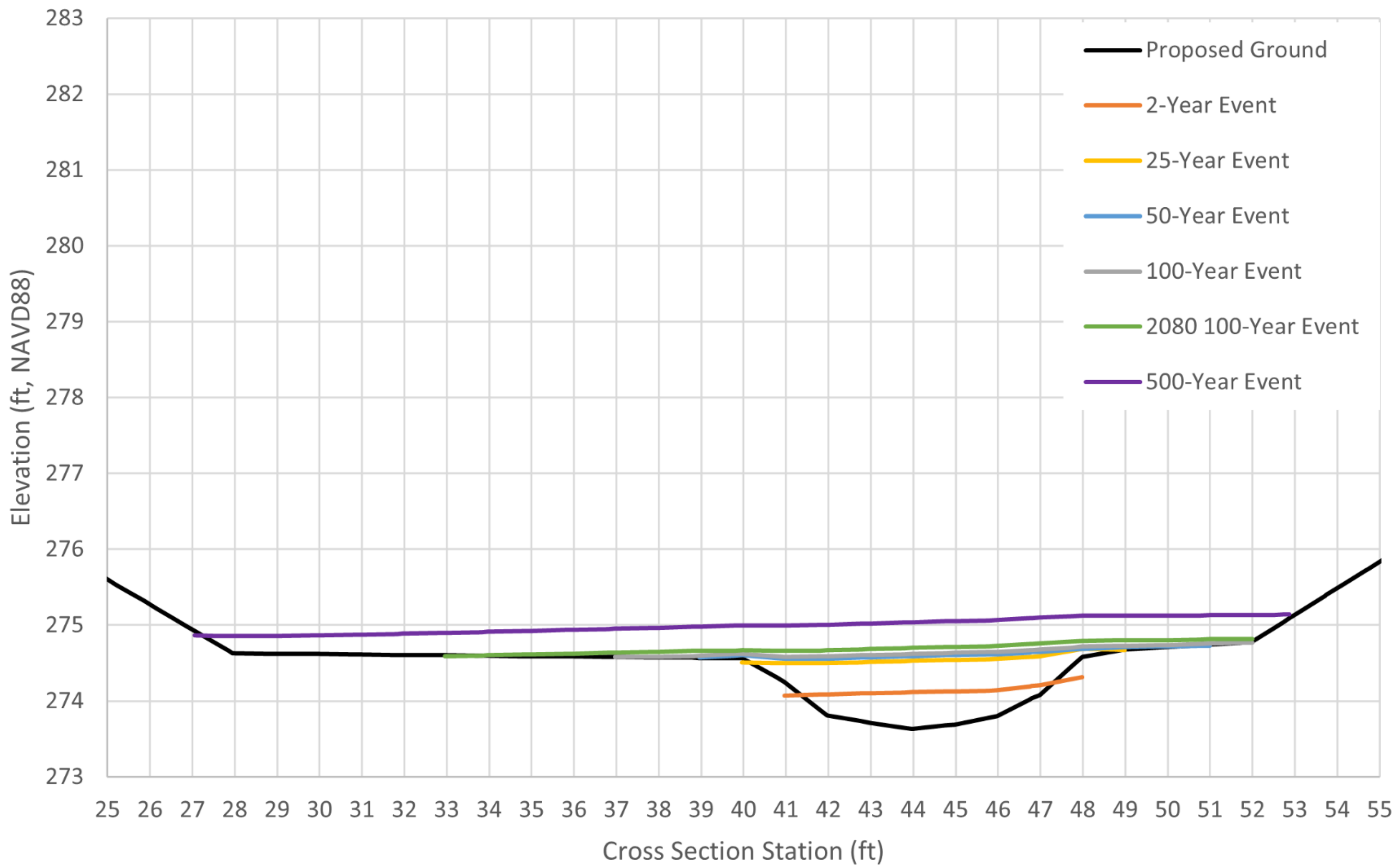


Figure 141: Typical Section Between I-5 Southbound and I-5 Northbound (Sta. 18+60)

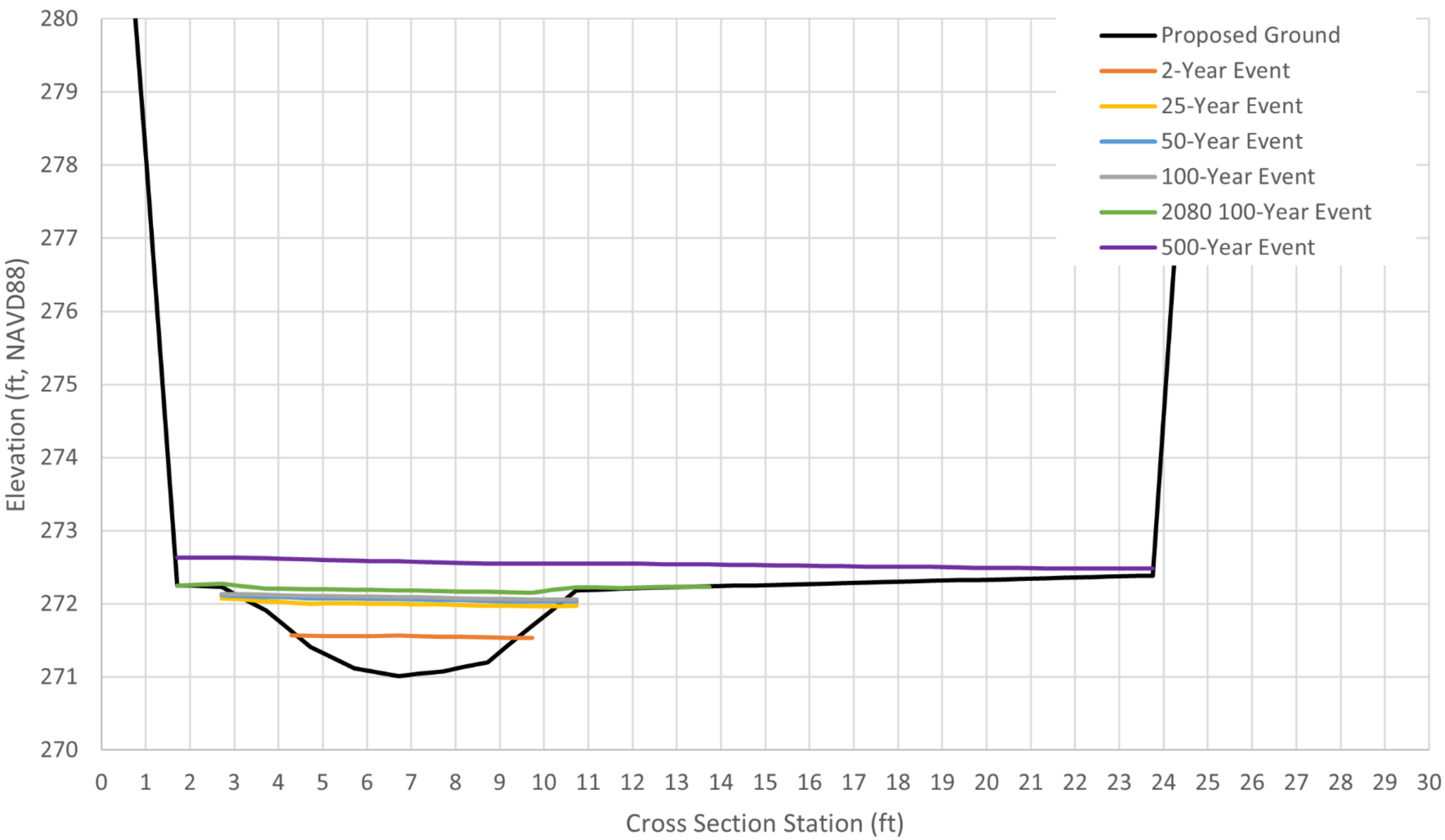


Figure 142: Typical Section in Structure 2 (Sta. 18+08)

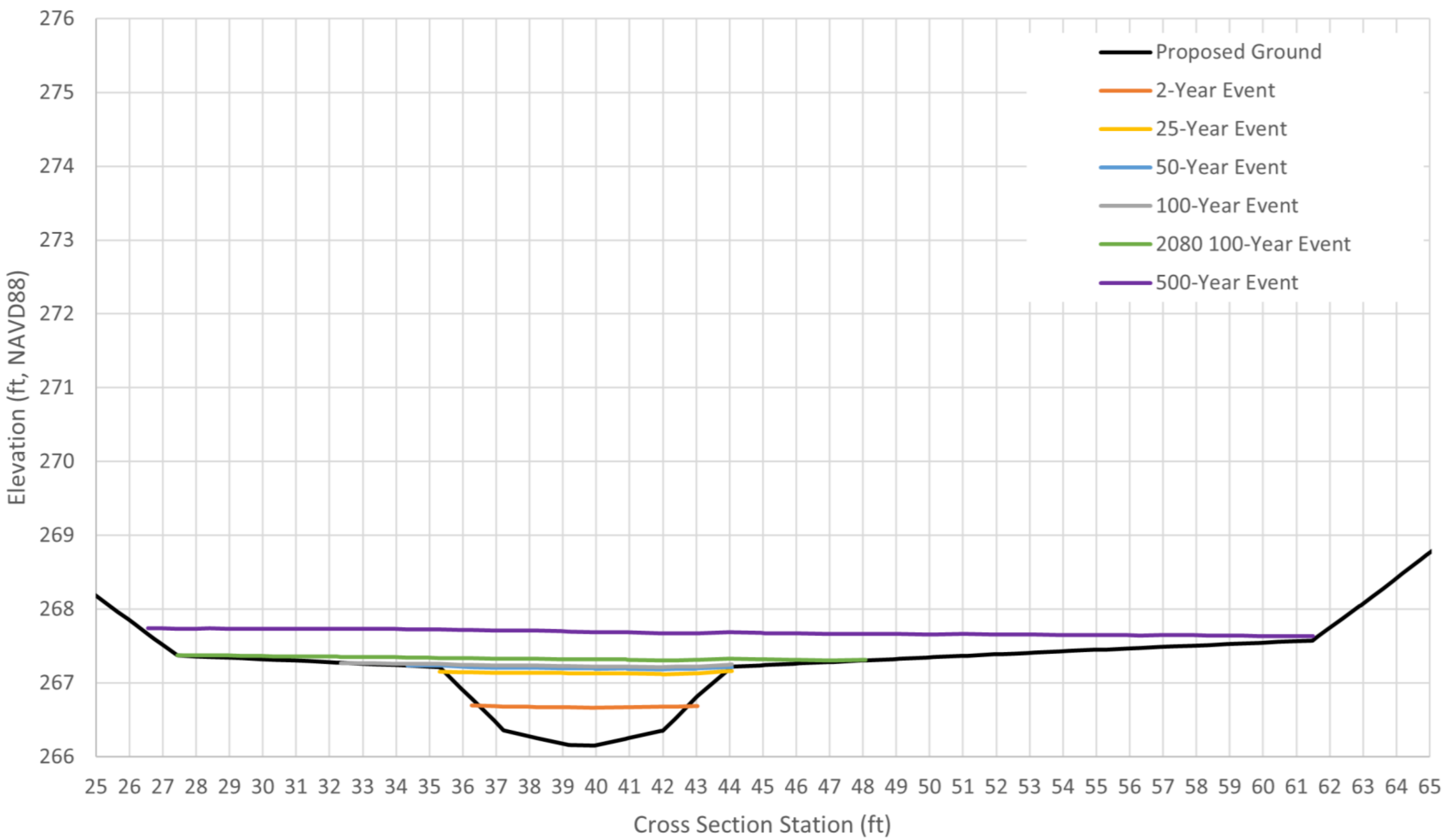


Figure 143: Typical Proposed Section Within Proposed Reach B, east of I-5 (Sta. 16+45)

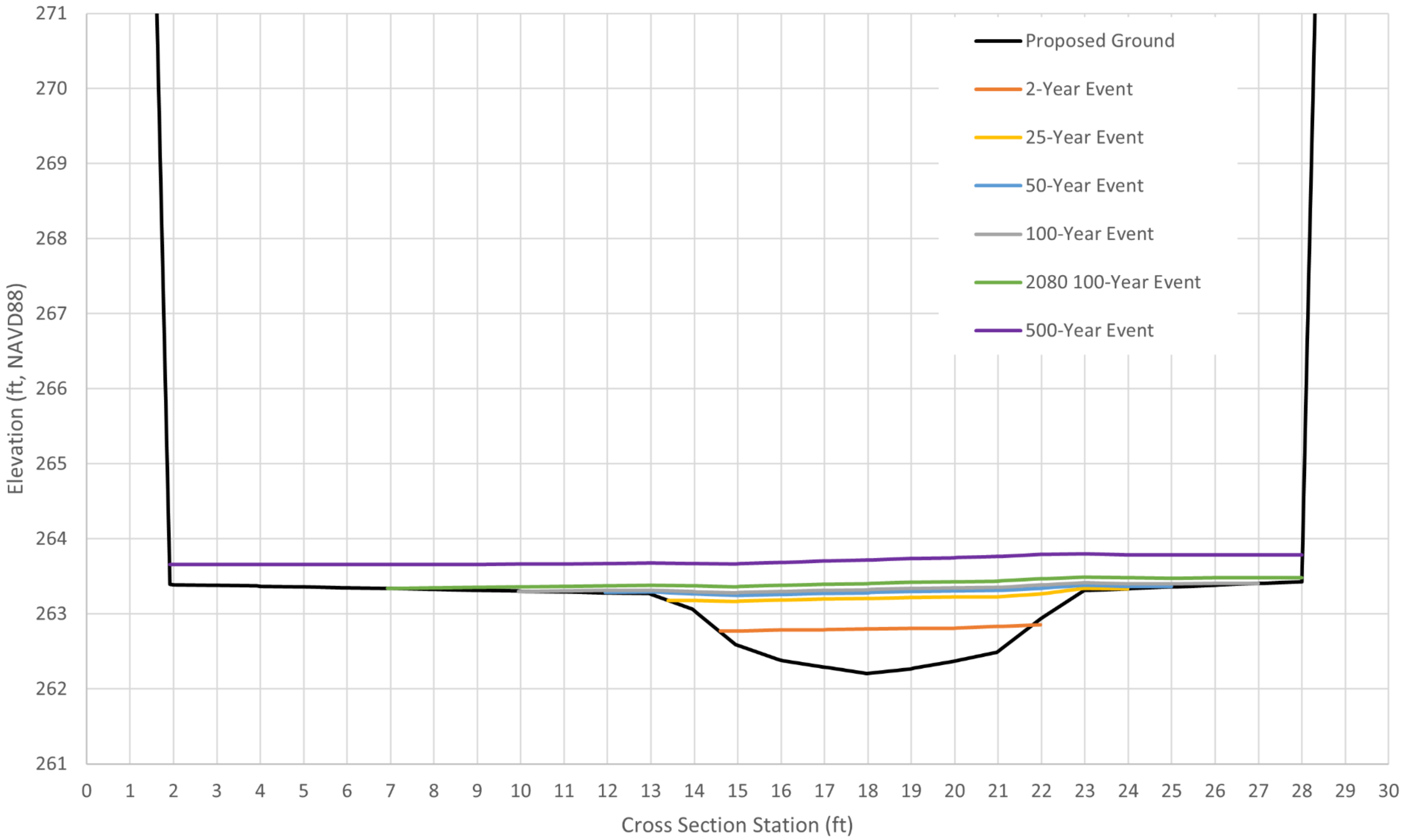


Figure 144: Typical Section Within Structure 3, under the I-5 Northbound Off-Ramp (Sta. 14+37)

Table 34: Proposed Velocities Including Floodplains at Select Cross Sections for the 100-Year Flow

	Q100 Average Velocities (ft/sec)		
	Left Overbank[a]	Main Channel	Right Overbank[a]
Reach A, Upstream (Sta. 23+13)	0.5	2.8	0.2
Upstream of Structure 1 (Sta. 20+20)	0.3	3.0	0.2
Structure 1 (Sta. 19+38)	0.8	3.4	0.3
Upstream of Structure 2 (Sta. 18+60)	0.5	3.1	0.5
Structure 2 (Sta. 18+07)	0.3	3.0	0.0
Downstream of Structure 2 (Sta. 17+66)	0.4	2.2	0.4
Reach B (Sta. 16+45)	0.2	2.2	0.1
Upstream of Structure 3 (Sta. 15+50)	1.4	2.5	0.7
Structure 3 (Sta. 14+36)	0.8	3.4	0.8
Downstream of Structure 3 (Sta. 13+07)	0.9	3.5	0.6

a. Left overbank and right overbank locations determined from Proposed Conditions Q2 extent.

Table 35: Proposed Velocities Including Floodplains at Select Cross Sections for the 2080 Project 100-Year Flow

	2080 Q100 Average Velocities (ft/sec)		
	Left Overbank[a]	Main Channel	Right Overbank[a]
Reach A, Upstream (Sta. 23+13)	0.6	3.0	0.2
Upstream of Structure 1 (Sta. 20+20)	0.5	3.4	0.3
Structure 1 (Sta. 19+38)	1.3	3.7	0.6
Upstream of Structure 2 (Sta. 18+60)	0.7	3.4	1.0
Structure 2 (Sta. 18+07)	0.8	3.4	0.4
Downstream of Structure 2 (Sta. 17+66)	0.5	2.4	0.6
Reach B (Sta. 16+45)	0.4	2.5	0.4
Upstream of Structure 3 (Sta. 15+50)	1.6	2.7	0.9
Structure 3 (Sta. 14+36)	0.8	3.6	1.1
Downstream of Structure 3 (Sta. 13+07)	1.0	3.5	0.7

a. Left overbank and right overbank locations determined from Proposed Conditions Q2 extent.

Figure 145: Proposed Conditions 2080 Predicted 100-Year Velocity Map (upstream)

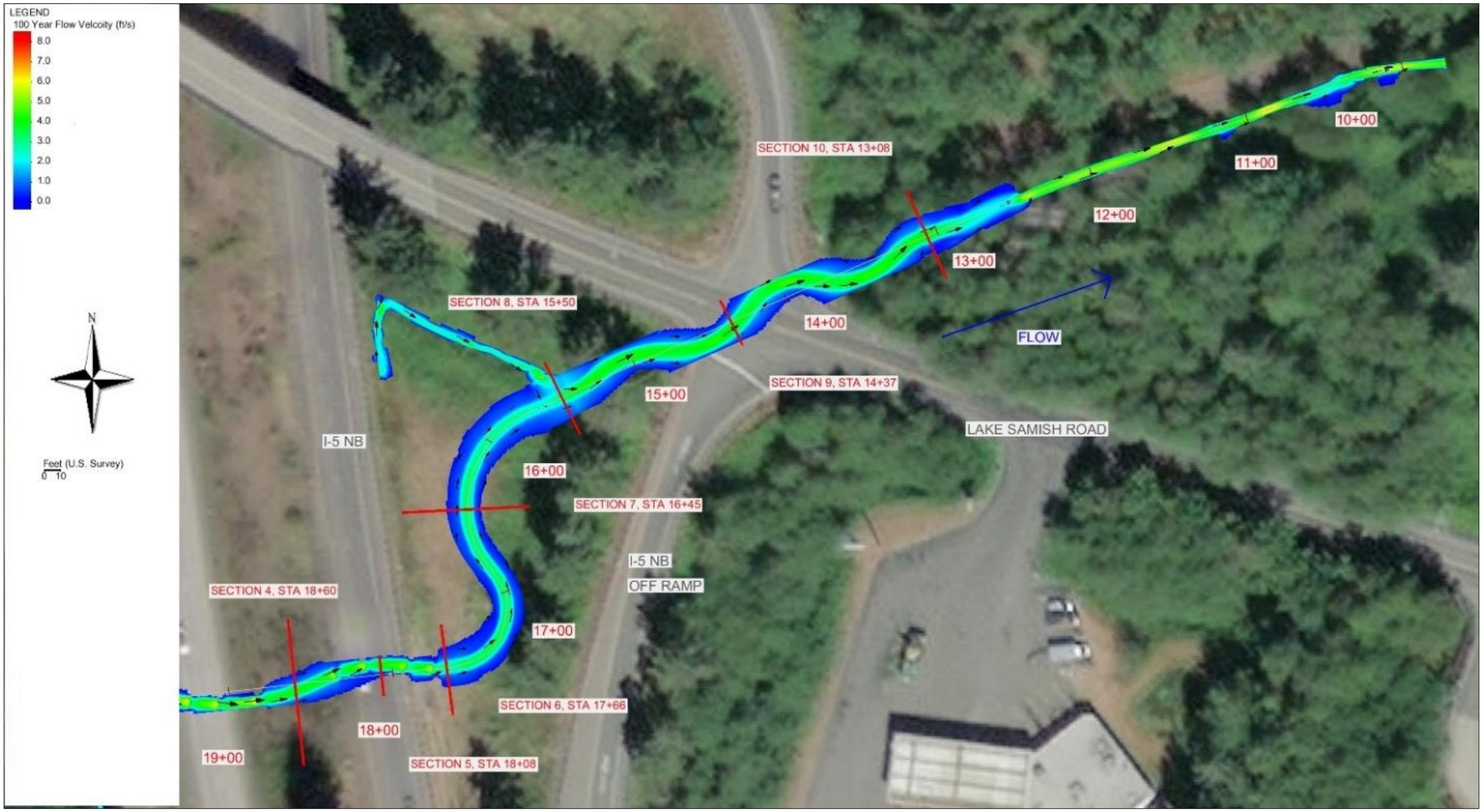


Figure 146: Proposed Conditions 2080 Predicted 100-Year Velocity Map (downstream)

4.7 Water Crossing Design

4.7.1 Structure Type

No structure type has been recommended by Headquarters Hydraulics. The layout and structure type will be determined at later project phases.

4.7.2 Minimum Hydraulic Opening Width and Length

Structure 1 and Structure 2 within Proposed Reach A are designed to have a 24-foot minimum hydraulic opening. This is an increase from the WCDG Equation 3.2 calculation to provide a stream plan form through the crossings similar to the Upstream Reference Reach as discussed in Section 4.4.2. The additional width also reduces the length-to-width ratio below 10 for Structure 1 (Table 36). The velocity ratios relative to the upstream channel are shown as 1.1 for Structure 1 in Table 37 and 1.1 for Structure 2 in Table 38.

Structure 3 is designed to have a 28-foot minimum hydraulic opening as described in Section 4.6.2. The minimum hydraulic opening is proposed to provide a stream plan form similar to the Upstream Reference Reach but increased due to the slightly larger BFW and lower slope of the Downstream Design Reach.

The minimum 28-foot span for Structure 3 will provide the required hydraulic conditions for fish passage, as shown by the 100-year velocities. The ratio of the upstream velocity to the velocity in Structure 3 is 1.3 (Table 39). The velocities upstream of Structure 3 are low due to the wood placement and wider riparian bench. The modeled natural conditions 100-year average flow velocities within the Project Reach were 3.9 ft/sec and 4.0 ft/sec for the Downstream Reach. The modeled proposed 100-year average flow velocity of 3.6 ft/sec in Structure 3 is lower than the modeled natural conditions velocity, as well as the velocity in the Downstream Reach, and provides fish passage through the structure. The 28-foot minimum span for Structure 3 reduces the effects from a long structure, and reduces the length-to-width ratio of the structure to 8.3.

Based on the factors described above, a minimum hydraulic opening of 24 feet for Structures 1 and 2 and of 28 feet for Structure 3 was determined to be necessary to allow for the stream plan form and channel complexity required to match the Upstream Reference Reach and Downstream Design Reach, respectively. The projected 2080 100-year flow event was evaluated and the velocity comparisons for these flow rates can be seen in Table 37 through Table 39.

Table 36: Proposed Length, Hydraulic Opening, and Length to Width Ratio by Structure

	Proposed Length (feet)	Proposed Hydraulic Opening (feet)	Length-to-Width Ratio
Structure 1	131	24	5.5
Structure 2	66	24	2.8
Structure 3	232	28	8.3

Table 37: Velocity Comparison for Structure 1, 24-Foot Span Structure

	100-Year Velocity (ft/sec)	Projected 100-Year Velocity (ft/sec)	Difference (ft/sec)
Upstream of Structure	3.0	3.4	0.3
Through Structure	3.4	3.7	0.3
Downstream of Structure	3.1	3.4	0.2
Velocity Ratio (Structure/Upstream)	1.1	1.1	N/A

Table 38: Velocity Comparison for Structure 2, 24-Foot Span Structure

	100-Year Velocity (ft/sec)	Projected 100-Year Velocity (ft/sec)	Difference (ft/sec)
Upstream of Structure	3.1	3.4	0.2
Through Structure	3.0	3.4	0.4
Downstream of Structure	2.2	2.4	0.2
Velocity Ratio (Structure/Upstream)	1.0	1.0	N/A

Table 39: Velocity Comparison for Structure 3, 28-Foot Span Structure

	100-Year Velocity (ft/sec)	Projected 100-Year Velocity (ft/sec)	Difference (ft/sec)
Upstream of Structure	2.5	2.7	0.1
Through Structure	3.4	3.6	0.3
Downstream of Structure	3.5	3.5	0.1
Velocity Ratio (Structure/Upstream)	1.3	1.3	N/A

No size increase was determined to be necessary to accommodate climate change.

A minimum hydraulic opening of 24 feet is recommended up to a maximum structure length of 240 feet, or a 10:1 length-to-width ratio. For Structure 3, the minimum hydraulic opening of 28 feet is recommended up to a maximum structure length of 280 feet, or a 10:1 length-to-width ratio. If the length is increased beyond these recommendations, then additional structure width should be evaluated to reduce effects of the structure length.

4.7.3 Freeboard

The WCDG recommend the prevention of excessive backwater rise and increased main channel velocities during floods that might lead to scour of the streambed, the coarsening of the stream substrate, and the allowing the free passage of debris expected to be encountered. A minimum of 3 feet of freeboard is required for structures greater than 20 feet long per the WSDOT *Hydraulics Manual*. WSDOT is incorporating climate resiliency in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE.

Proposed Reach A

The minimum required freeboard for Proposed Reach A is 3 feet at the 100-year flow event. The WSE is projected to increase by about 0.1 foot for the 2080 projected 100-year flow rate. The provided freeboard is at least 4 feet for the 100-year WSE; therefore, no additional increase in freeboard was required at this site to accommodate climate resilience.

A minimum 5-foot vertical clearance is designed for the minimum hydraulic opening for Structure 1. The vertical clearance is measured from the highest grade within the structure to the minimum inside ceiling of the structure. This minimum vertical clearance is based on an assumed 3-foot height from the inside ceiling of the structure to the lowest point of the existing road surface, or about 2 feet depth of cover over a structure top slab that is 1 foot thick. The vertical clearance for Structure 2 is designed as a minimum of 4 feet based on the minimum existing road grade over the structure. The proposed vertical clearances are based on the existing road grade due to the length of potential effects that would likely be required to increase the grade of the I-5 roadway at the structures.

If feasible, the vertical clearance for Structures 1 and 2 should be increased to the target 6-foot minimum maintenance clearance per WSDOT *Hydraulics Manual* Section 7-4.5.2 (WSDOT 2022a) during later phases of design. The 2 feet of assumed cover over the structure should be evaluated if it can be reduced based on design of the structure for traffic loading to increase vertical clearance within Structure 1 and Structure 2.

Long-term degradation, aggregation, and debris risk were also evaluated at this location. The stream crossings present a low risk of long-term degradation with the large wood placement in the open channels and the step-pools within the structures to provide roughness and stability. Long-term degradation potential was evaluated, as discussed below, for Proposed Reach B.

Proposed Reach B

The minimum required freeboard for Proposed Reach B is 3 feet at the 100-year flow event. The WSE is projected to increase by about 0.1 foot for the 2080 projected 100-year flow rate. A minimum vertical clearance of 6 feet between the maximum streambed grade at the edge of the minimum hydraulic opening and the inside top of Structure 3 is proposed. Increasing the vertical clearance to 10 feet for equipment access should be evaluated as a part of later phases of design based on the height of the road embankment. The freeboard is at least 4 feet for the

100-year WSE; therefore, no additional increase in freeboard was required at this site to accommodate climate resilience.

Long-term aggradation potential was evaluated for Proposed Reach B. The long-term aggradation potential was estimated as 2 to 4 feet of sediment depth and is described in Section 8.2.4.

4.7.3.2 Past Maintenance Records

As discussed previously, WSDOT Area 1 Maintenance was contacted to determine whether there were ongoing maintenance problems at the existing structures due to LWM racking at the inlets or sedimentation. The maintenance representative indicated that an estimated 15 cubic yards of sediment had been removed from the outlet of Culvert 995232 in 2018 (Case, personal communication, April 21, 2021).

4.7.3.3 Wood and Sediment Supply

The potential for the South Tributary to transport LWM is very low, given the relatively low stream flows. Both small woody material and LWM are present in the Upstream Reference Reach, which has an 8.1 percent average slope, and there has been no evidence found that the stream has transported significant wood material down to I-5. The LWM proposed for the project will be evaluated for stability as a part of the FHD level of design.

The upstream property was logged between 1976 and 1981. Therefore there is the potential that changes in land cover in the future, could affect the stability of the stream. The most likely outcome from changes in future land cover, such as logging upstream, would be increased sediment transported from the upstream hillside that would deposit in Reach B within the median.

The stream channel profile has been designed to maintain steeper slopes through the I-5/Lake Samish Road interchange, with the slope flattening out downstream of I-5. This promotes sediment transport capacity to the extent feasible through the interchange and allows sediment deposition downstream of the I-5 northbound lanes within the median, where sediment can be more easily removed. Regular dredging for sediment removal is not anticipated to be needed. The proposed design widens the floodplain within the median to maximize the area in which sediment can naturally deposit during peak flow events, and this will increase ability for stream meandering over time.

A design option with a wider floodplain on the south side of the existing channel, downstream of Structure 3, was evaluated for a potential area for additional sediment deposition. Conservative estimates, based on a 20-foot-wide floodplain on the south side above the existing channel banks, showed the area would allow for approximately 40 cubic yards of sediment deposition. Due to the unknown upstream sediment supply and amount of fines that would expect to be transported at peak flow events, it is not clear if the benefit of increasing the floodplain width would warrant the necessary property acquisition and grading. A detailed sediment transport analysis will be conducted prior to beginning the FHD phase of the project. That analysis will provide estimates of anticipated sediment supply to inform the potential effects of widening the floodplain downstream of Structure 3. With either the proposed design or the proposed design with the additional floodplain grading described above, regular maintenance for sediment removal in not anticipated downstream Structure 3.

4.7.3.4 Flooding

The South Tributary is not located within a mapped FEMA floodplain. There is the potential for the undersized culverts to become clogged with debris, pond, and overtop into the adjacent roadside ditches. The only modeled event in which I-5 overtopped from flows was the 500-year flow event in the existing conditions hydraulic analysis. The proposed conditions stream channel and culvert will significantly improve conveyance capacity through the interchange, and hydraulic analyses indicate no flooding potential under the proposed conditions.

4.7.3.5 Future Corridor Plans

There are currently no long-term plans to improve I-5 through this corridor.

5 Streambed Design

5.1 Bed Material

The realigned stream channel for the South Tributary consists of slopes of 4 percent to 8.1 percent under I-5 and immediately upstream (Proposed Reach A), transitioning to slopes of 3 percent down to 1.7 percent within the I-5 northbound off-ramp crossing (Proposed Reach B). The existing Upstream Reference Reach, with an 8.1 percent slope, is considered the reference reach for Proposed Reach A. The Downstream Design Reach, downstream of the culvert under Barleen Road, is considered to be the design reach for Reach B.

The proposed streambed materials were developed using the observed streambed material data described in Section 2.8.3 for the Upstream Reference Reach and Downstream Design Reach. The unit-discharge bed material equation (Barnard et al. 2013) was used for comparison with the proposed stream gradations for Proposed Reach A, in accordance with the WSDOT *Hydraulics Manual* (2022a). The Modified Critical Shear Stress from the U.S. Forest Service (USDA 2008) was calculated for Proposed Reach B, for slopes less than 4 percent in accordance with WSDOT (2022a).

5.1.1 Site Constraints

At the project site, the site constraints include the I-5 crossing and the I-5/Lake Samish Road interchange. No natural or anthropogenic site constraints were identified either immediately upstream or downstream of the project site that may limit the streambed design at the project site. Based on the initial surficial geology information, the project site consists of till indicating the channel bed should be relatively resistant to vertical adjustments over time. However, more recent borings along the proposed alignment indicate the presence of soils that are more erodible (WSDOT 2022c) and could result in greater vertical adjustment over the lifespan of the project. Without results of a full geotechnical analysis, it was assumed for the PHD that no constraints were identified to prohibit natural channel adjustments. Therefore, a risk assessment is not necessary for the South Tributary culvert replacements for informing the streambed design per the WSDOT Appendix 7A Streambed Material Decision Tree (WSDOT 2022a). A full geotechnical analysis will be completed in a later design phase. Results will reveal the depth and consistency of the till layer and will provide more information related to potential natural channel adjustments.

5.1.2 Streambed Material Decision Tree

No significant constraints were identified upstream or downstream of the Project Reach for the South Tributary. Therefore the streambed material is designed to meet stream simulation requirements per the Streambed Material Decision Tree in WSDOT (2022a) Appendix 7A.

5.1.3 *Proposed Streambed Sediment Sizing*

The proposed streambed material was developed to match within 20 percent of the D_{50} to meet stream simulation requirements. The Bathurst Method (Barnard et al. 2013) and the Modified Critical Shear Stress method (USDA 2008) were also evaluated for the Upstream Reference Reach and Downstream Design Reach, respectively, for comparison with the developed design gradations.

Proposed Reach A

Three surface pebble counts were collected within the Upstream Reference Reach (Figure 32). The average diameters of the three measurements are presented in Table 40. Detailed results of the pebble counts are discussed in detail in Section 2.8.3.

The average D_{50} of the observed upstream bed material was 0.84 inch, and the average D_{84} was 2.17 inches. The proposed streambed material for Proposed Reach A is recommended as approximately 80 percent WSDOT Streambed Sediment, with 20 percent WSDOT 8-inch Streambed Cobbles.

The unit-discharge bed design method (Barnard et al. 2013) uses the Bathurst equation to predict the size of a D_{84} particle that would be on the threshold of motion for a given unit discharge. The equation is considered to apply to streams with a gradient of 4 percent or greater. The equation predicts the D_{84} particle as follows:

$$D_{84} = 3.54S^{0.747}(1.25q_c)^{2/3}/g^{1/3}$$

Where:

D84 = *Intermediate axis of the 84th percentile particle*

S = *Energy slope of the proposed channel, foot/feet*

qc = *The critical unit discharge (total design discharge divided by the width of the bankfull channel) at which incipient motion of D84 occurs, in cfs per foot. Design of the 100-year flood/storm.*

G = *The acceleration of gravity, feet/sec2*

Using the relationships presented in the WCDG (Barnard et al. 2013); where:

D_{84}/D_{100} = 0.4 **Equation 3.6**

D_{84}/D_{50} = 2.5 **Equation 3.7**

D_{84}/D_{16} = 8.0 **Equation 3.8**

Based on the Bathurst equation, the calculated D_{84} is 4.4 inches. Using this D_{84}, the resulting D_{16}, D_{50}, and D_{100} are shown in Table 40. A non-porous bed mix must have a minimum of 5 percent to a maximum of 10 percent fines in the mix (Barnard et al. 2013). The proposed streambed material for Proposed Reach A is compared to the observed gradations and the Bathurst equation in Table 40. The Fuller-Thompson equation from WDFW (Barnard et al. 2013) for a well-graded sediment mix is also shown for reference in Figure 147. The proposed streambed material gradation is based on the measured gravel sizes from the Upstream Reference Reach; therefore, the proposed gradation is less than the predicted values from the Bathurst equation in order to approximate the native bed material observed in the Reference Reach in accordance with stream simulation guidelines. In addition to the described streambed gradation, abundant amounts of organics, such as small woody material, will be incorporated into the streambed mix and on the surface throughout the proposed channel to help support the formation of beneficial habitat features for fish.

Calculations were performed using the Modified Shields method (USDA 2008) to determine mobility of the streambed material in the Upstream Reference Reach and within Proposed Reach A. The Proposed Reach A streambed material is mobile at the same flows as the Reference Reach, occurring during the 2-year flow event and larger for the D_{84} particle. Therefore, the proposed streambed material is in accordance with stream simulation guidelines by approximating the mobility of the Reference Reach and will restore sediment continuity through the structure crossings.

Table 40: Comparison of Observed and Proposed Streambed Material for Proposed Reach A

	Upstream Field Measured Streambed Material Average Diameter (inches)	WCDG Equations (3.6, 3.7, 3.8) Diameter (inches)	Proposed Reach A Streambed Material Diameter (inches)
D_{16}	0.3	0.6	0.1
D_{50}	0.8	1.8	0.9
D_{84}	2.2	4.4	2.4
D_{100}	7.1	11.0	7.4

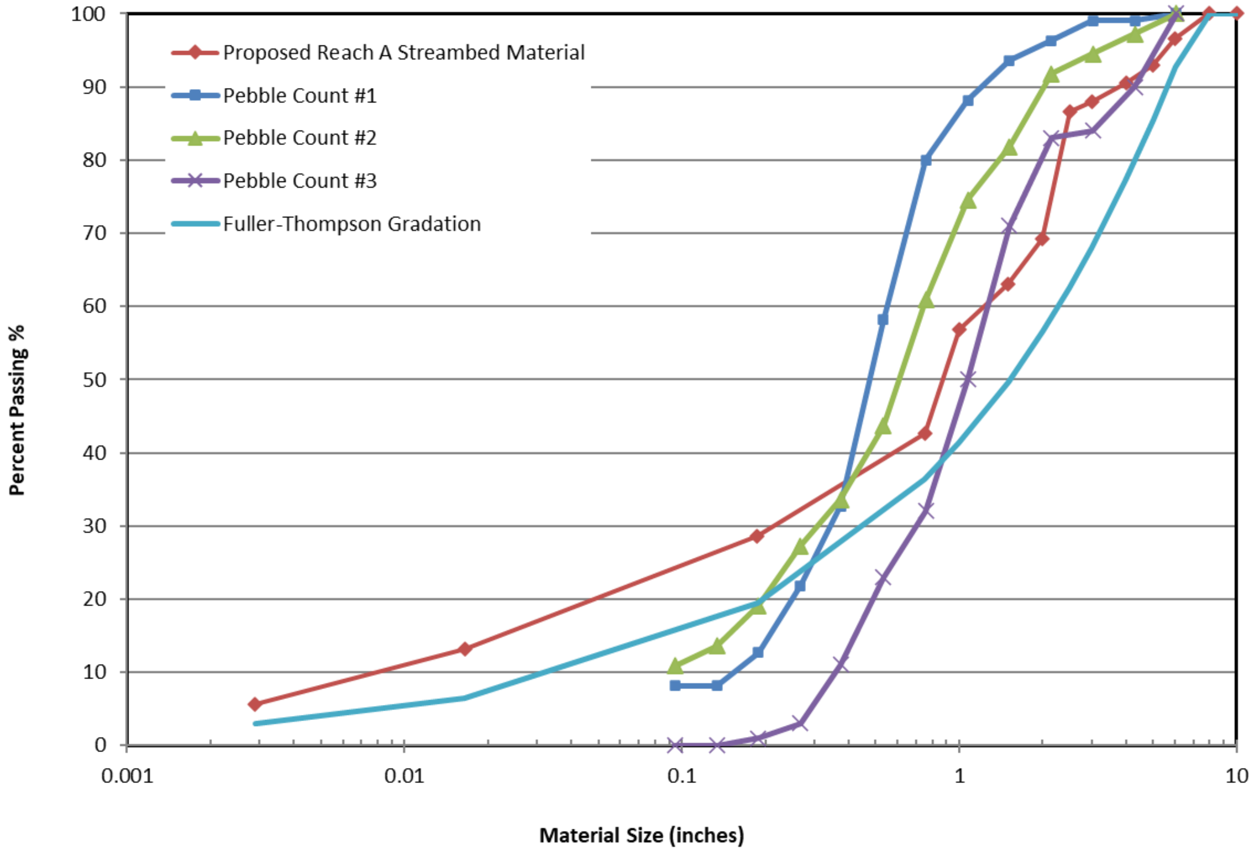


Figure 147: Comparison of Proposed Upstream Bed Material to Pebble Counts and Fuller-Thompson Gradation

Proposed Reach B

In Proposed Reach B, the stream slope transitions to approximately 2 to 3 percent, and then about 1.7 percent slope through the I-5 northbound off-ramp culvert (995245). Due to the lower slopes, the streambed material within the Downstream Design Reach is considered to be the most representative for Proposed Reach B. The existing streambed gravel in the Design Reach consists of sand and fine to coarse gravel, based on Pebble Count #6 (described in Section 2.8.3).

The WSDOT Appendix 7A Streambed Material Decision Tree (WSDOT 2022a) was evaluated for Proposed Reach B, and the Proposed Reach B streambed gravel can approximate the Downstream Design Reach streambed material without significant constraints. The D_{50} of the Design Reach is 0.44 inch, which is finer than the WSDOT Streambed Sediment gradation D_{50} of approximately 0.68 inch. The WSDOT Streambed Sediment is generally considered to be spawning gravel. The proposed streambed material for Proposed Reach B is compared to the observed gradations in the Downstream Design Reach in Table 41 and shown in Figure 148.

Therefore, a 100 percent WSDOT Streambed Sediment gradation is recommended for Proposed Reach B to improve upon and provide spawning gravels for the lower reaches of the design. Finer material is likely to deposit in these areas from upstream over time, adding fine material back into the streambed. Additionally, abundant amounts of organics, such as small woody material, will be incorporated both on the surface and within the streambed for Proposed Reach B to help support the formation of beneficial habitat features for fish.

Table 41: Comparison of Observed and Proposed Streambed Material for Proposed Reach B

	Downstream Design Reach Streambed Material Average Diameter (inches)	Proposed Reach B Streambed Material Diameter (inches)
D_{16}	0.1	0.02
D_{50}	0.4	0.7
D_{84}	1.1	2.1
D_{100}	2.5	2.5

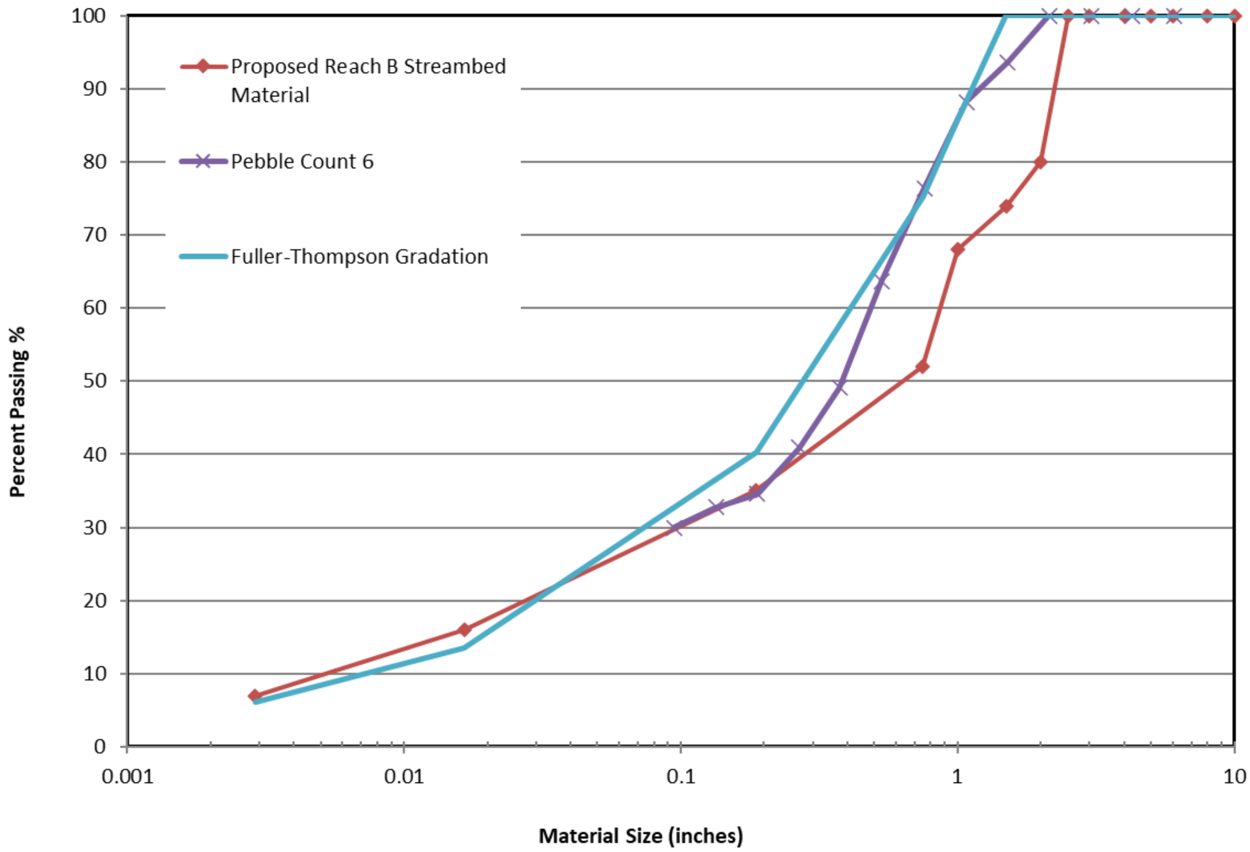


Figure 148: Comparison of Proposed Reach B to Downstream Design Reach Pebble Count and Fuller-Thompson Gradation

The Modified Shields method from the U.S. Forest Service (USDA 2008) was used to calculate the mobility of the D_{84} particle size in the Downstream Reach under existing conditions. The calculation shows that the existing bed material in that reach is mobile during 2-year flows and larger based on the shear stress and the D_{84} particle of approximately 1.1 inches. The proposed streambed sediment gradation for Proposed Reach B was calculated to be mobile during the 2-year event and larger flows based on the D_{84} particle size of 2.1 inches. There are no significant constraints identified that would prevent bed mobility in the lower reaches; therefore, the bed gradation is intended to be mobile in the lower reaches to meet stream simulation guidelines.

The Modified Shields method was also used to calculate the mobility of the particle sizes for the streambed gravel. The calculations are included in Appendix D. The critical particle size for mobility based on the calculations is shown in Table 42. The calculations indicate that the entire range of particles in the proposed streambed mix (D_{50} = 0.9 inch, D_{100} = 8 inches) is mobile for the 2-year and larger flows, for slopes greater than 4.1 percent. Large wood placement and deformable grade controls in Proposed Reach A will promote sediment retention and will provide stability of the stream gravel in some areas. The proposed streambed gravel and buried slash are intended to have similar mobility as the bed material and small wood observed in the Upstream Reference Reach.

A 2-year peak flow will mobilize the streambed gravel up to the 5-inch cobble size in Structure 2, and up to a 4-inch cobble in the Proposed Reach B stream channel. The 2-year event will mobilize up to a 1-inch cobble size in Structure 3. The results indicate that cobbles of approximately 2 inches and larger are expected to deposit within Structure 3 or upstream during a 2-year peak flow event. The results indicate that a 100-year event has the transport capacity to mobilize up to the 8-inch cobble size within the streambed gravel downstream of Structure 3, based on the D_{50} of 0.9 inch.

Table 42: Calculated Maximum Mobile Particle Size for Streambed Gravel Gradation with D_{50} of 0.9 Inch

Peak Flow	Proposed Reach A, Structure 1, S=6.3%	Proposed Reach A, Structure 2, S=4.1%	Proposed Reach B, S=2.6%	Proposed Reach B, Structure 3, S=1.7%
2-year	8 inches	5 inches	4 inches	1 inch
25-year	8 inches	8 inches	8 inches	6 inches
50-year	8 inches	8 inches	8 inches	6 inches
100-year	8 inches	8 inches	8 inches	8 inches

5.1.4 Step-Pools

Structure 1 and Structure 2 are proposed with step-pool morphology following measurements from the step-pools observed in the Upstream Reference Reach (see Section 2.8.1 and Table 6). Preliminary conceptual information for the step-pool design is provided in this report and should be evaluated further in later stages of design.

The step-pools are intended to be stable features inside the proposed structures. The steps are proposed as streambed boulders, with cobbles and buried slash, to emulate the observations from the Upstream Reference Reach. The boulders measured in the Reference Reach were typically from approximately 10 inches in diameter up to 16 inches in diameter. The boulders forming the step-pools in the Reference Reach are considered stable based on the observations described in Section 2.8.1.

The boulders within Structure 1 and Structure 2 must be designed to be stable for peak flows up to the 100-year event. The calculations for the proposed boulder steps within Structures 1 and 2 indicate that the boulder steps will be stable up through the 100-year event with a D_{50} of at least 11.3 inches (Appendix D) or 0.9 foot in diameter. Therefore, WSDOT One-Man and Two-Man Streambed Boulders are proposed to provide a minimum boulder size of 12 inches for stability.

The boulder placement should be designed and constructed to maintain a gap between boulders (e.g., a minimum of 0.5 foot) within the BFW channel to maintain a low-flow thalweg and prevent a fish barrier from forming. The boulders are also intended to be placed to form a short cascade (e.g., 2H:1V) to the pool bottom to prevent an actual vertical drop from forming. Large cobbles and buried slash should be mixed in with the stream bed boulders to backfill the gaps and provide steps that function similar to those existing in the Upstream Reference Reach. The conceptual design of the step-pools within the structures is shown in Figure 149.

The typical spacing of the steps, the step height, and the typical pool length and depth in the preliminary design are shown in Table 43 and are based on the data from the Upstream Reference Reach (Table 6). The typical spacing for the steps in the preliminary design is between approximately 15 feet and 24 feet, with step heights from the top of the step to the pool bottom of approximately 1.0 foot, and typical pool depths of 0.5 foot and lengths of 4 feet. The run from the end of the pool to the next step varies in length from approximately 11 feet to 20 feet, and the longitudinal slopes of the runs vary from 1.1 percent to 5.2 percent (Table 43).

Table 43: Typical Dimensions from Preliminary Step-Pool Concept Within Structure 1 and Structure 2

Structure	Typical Step Spacing (feet)	Typical Step Height (feet)	Typical Pool Depth (feet)	Typical Pool Length (feet)	Typical Run Length (feet)	Typical Run Slope (%)
Structure 1 (Average 6.3% Slope)	16–24	1.0	0.5	4.0	12–20	4.4–5.2
Structure 2 (Average 4.0% Slope)	15–24	1.0	0.5	4.0	11–20	1.1–2.3

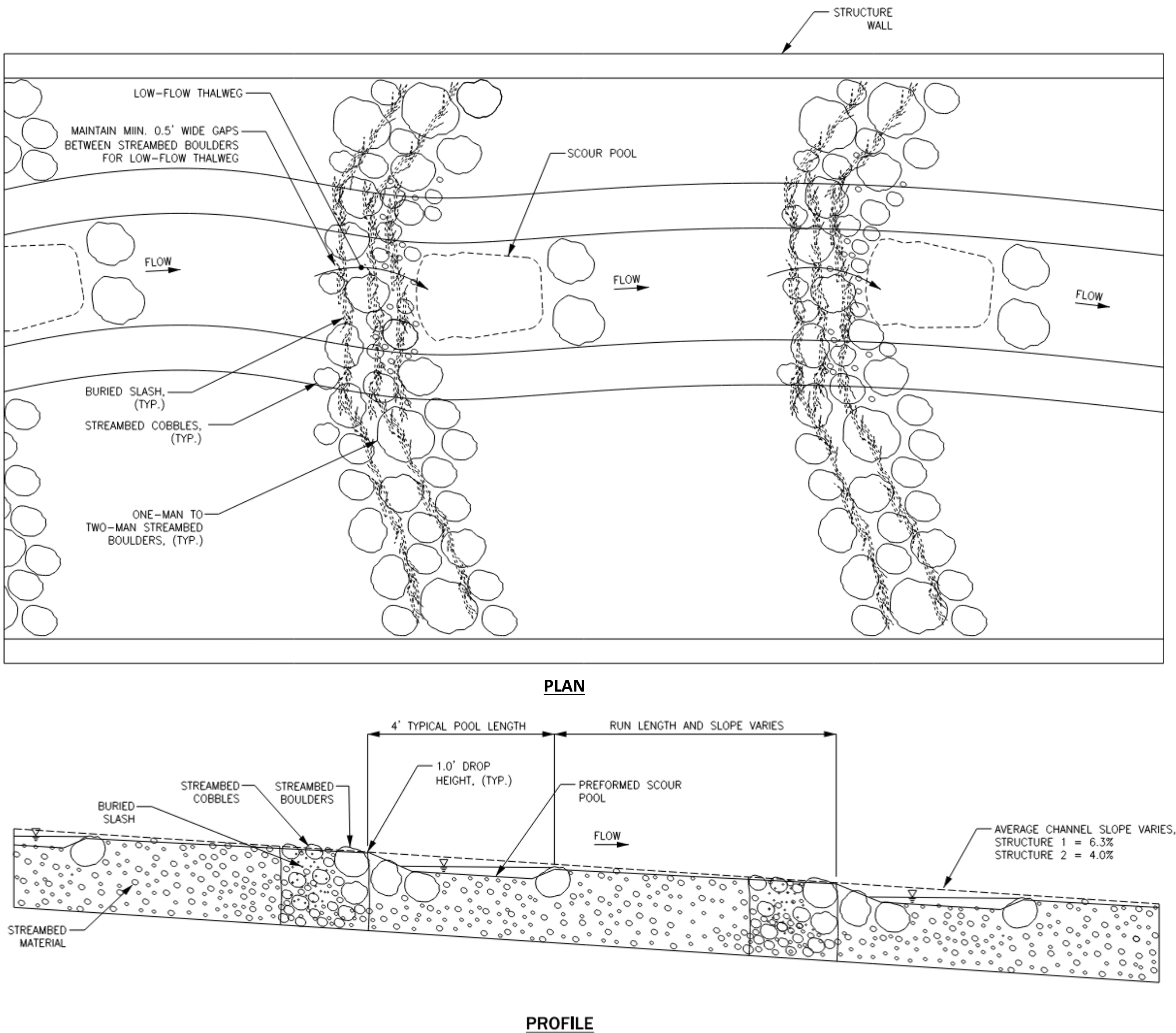


Figure 149: Preliminary Concept for Step-Pools Within Structure 1 and Structure 2

5.1.5 Meander Bars

Meander bars with boulders and buried slash are proposed within Structure 3 to provide forcing elements that promote scour pool formation, provide sediment sorting, and maintain the low-flow thalweg.

The meander bars are designed using the WSDOT guidance for meander bars in stream simulation design (WSDOT 2022b). The slope of Structure 3 is 1.7 percent, which falls within the 1 to 3 percent range to mimic the typical stream characteristics of riffle-pool systems. The proposed meander bars are spaced approximately 50 to 60 feet apart to provide the proposed sinuosity of about 1.04 within Structure 3, as described in Section 4.4.2. The 28-foot minimum hydraulic opening for Structure 3 with meander bars provides the stream planform and sinuosity through the crossing without requiring the BFW channel to contact the structure walls.

The meander bars are proposed with an approximate width of 10 feet at the streambed elevation, which presents a constriction of approximately 36 percent of the 28-foot-wide minimum hydraulic opening of Structure 3. This is within the 30 to 50 percent range for the constriction of the structure width outlined in the guidance for meander bars (WSDOT 2022b). The 2-year peak flow is approximately 7.4 feet wide within Structure 3, and, therefore, meander bars are intended to constrict the stream below this width only at locations where a scour pool is planned.

The shape of the proposed meander bars is shown with a crown, deflecting head, and tapering tail following WSDOT (2022b) guidance. The coarse cobbles for the top of the meander bar should be designed at the 10-year flow elevation, which would be approximately 1.0 foot above the thalweg elevation, or the approximate grade of the overbank within the Structure 3 crossing. The stream is modeled to contact the structure wall at the 50-year peak flow event.

The Modified Shields method (USDA 2008) was used to determine the meander bar gradation that will be stable during the 100-year peak flow based on critical shear stress. The calculated gradation for the meander bars consists of a D_{50} of approximately 1.8 inches and a D_{84} of 5.2 inches and should consist of a well-graded mixture of streambed materials. The proposed gradation for the meander bars consists of 50 percent WSDOT 8-inch Streambed Cobbles and 50 percent WSDOT Streambed Sediment to approximate the calculated gradation (as shown in Table 44). The largest cobble size for the meander bar gradation is 8 inches; it is greater than twice the D_{100} of the streambed material (2.5 inches) because the 8-inch cobbles are required to achieve the stable D_{84} particle size of 5.2 inches.

Boulders meeting requirements for WSDOT One-Man and Two-Man Streambed Boulders, as well as buried slash, should be incorporated at the front of the meander bars to provide additional stability and encourage scour pool formation. The One-Man Streambed Boulders consist of rocks 12 to 18 inches in diameter. The Two-Man Streambed Boulders consist of 18- to 28-inch-diameter rocks.

The calculations for the meander bars in Structure 3, with a D_{50} of 1.8 inches, will be stable up through the 100-year peak flow event (Appendix D). The results indicate the 100-year peak flow event will mobilize up to a 1.3-inch cobble size, which is less than the D_{50} size of 1.8 inches. The mobility calculations for the meander bars are summarized for the Table 45.

Table 44: Meander Bars Gradation for Structures 1 and 2, with Slopes Greater than 4 Percent

	Meander Bars Gradation Average Diameter (inches)
D_{16}	0.1
D_{50}	1.8
D_{84}	5.2
D_{100}	8.0

Table 45: Calculated Maximum Mobile Particle Size for Meander Bars Within Structure 3, with D_{50} of 1.8 Inches

Peak Flow	Proposed Reach B, Structure 3, S=1.7%
2-year	0.2 inch
25-year	1.0 inch
50-year	1.0 inch
100-year	1.3 inches

5.2 Channel Complexity

5.2.1 Design Concept

LWM is proposed within the realigned stream to add channel and habitat complexity (see Figure 150 and Figure 151). The goal of the LWM placement is to promote pool formation, provide cover, retain sediment, and add roughness to reduce flow velocities.

Additional functions of the wood placement are to reconstruct stream channel mechanisms of the step-pool Upstream Reference Reach and to integrate with the riparian buffer. The preliminary large wood design is intended to form pools and provide cover habitat, as well as provide small wood that is typical of natural channels in western Washington. Multiple-log clusters and single logs with rootwads are proposed to improve channel sinuosity and complexity. These logs will also help provide bank and channel stability throughout the proposed channel. Small wood should be incorporated into the stream channel, such as in the form of buried slash for deformable grade controls.

Proposed Reach A

The Proposed Reach A complexity is intended to match the step-pool bed morphology of the Upstream Reference Reach. Species expected to be present above the I-5/Lake Samish Road interchange are resident fish, such as cutthroat trout, in addition to anadromous fish. The removal of the existing barriers combined with the proposed planform (Section 4.4.2) and profile (Section 4.4.4) will allow for anadromous fish access as described in Section 2.7.3. Large wood key pieces are proposed within Proposed Reach A as a forcing mechanism for the step-pool morphology, with additional wood pieces providing cover and complexity within the pools. Single streambed boulders may be placed in areas to provide additional complexity and stability, similar to conditions in the Reference Reach.

Buried slash should be incorporated into the streambed as deformable grade control to create step-pools in Proposed Reach A, similar to those in the Upstream Reference Reach. Deformable grade control for step-pool formation is proposed at changes in the stream profile slope and should also be constructed at intervals along Proposed Reach A similar to upstream. Buried slash should consist of small wood and brush up to 4 inches in diameter cleared from on site. Per WSDOT (2022a), small wood can also be placed in a riparian area cleared of trees between the edge of the active stream channel or floodway and the 100-year flood elevation. Small and large wood cleared from within the project area should be used in the reconstruction of the stream channel to the extent feasible.

The large wood design includes combinations of logs that vary in length and diameter. Logs with rootwads attached should be countersunk and placed in the low-flow channel to encourage maximum interaction with the stream. The ends of the logs are typically placed resting on the overbanks and hillslopes above the stream flows to be self-ballasting. Logs are intended to be placed with one end in contact with the streambed to create scour pools around the log. Some log ends are placed within the low-flow channel and countersunk to ensure flow engagement at low-flow events. Other logs are placed within the channel parallel to flow to promote thalweg formation along the log. Other logs are placed resting on top to provide additional cover and hiding habitat for juvenile fish. Typical placement details for woody material are shown in Figure 152.

Spawning habitat, over-winter habitat, rearing habitat, and floodplain interaction all require different aspects of wood placement. The project will address specific habitat components for fish by maintenance of the low-flow channel, creating pools and cover for fish (and invertebrates and insects) as refuge during high flows. Wood placement will help to encourage retention and deposition of fine sediments that are mobilized during the first storms of the year following construction. The risk of fish stranding during summer months is low due to placement of large wood to maintain the low-flow thalweg to allow access to the downstream reaches.

Proposed Reach B

For Proposed Reach B, a pool-riffle bed morphology is designed similar to the Downstream Design Reach, with pools and cover formed by the LWM. Large wood key pieces are proposed within Proposed Reach B to create the pool-riffle morphology for the 1 percent to 3 percent slopes, with additional wood pieces with rootwads providing cover and complexity within the pools. As with Proposed Reach A, some rootwads and wood will be countersunk and remain engaged at low flows to better approximate natural in-channel wood. Buried slash should also be incorporated into the streambed as a part of the pool-riffles in Proposed Reach B.

Adult and juvenile fish may be found in the lower reaches of the restored stream channel. Juvenile rearing can be expected within the lower slopes in the downstream reaches of the project area (Proposed Reach B). During high flows, juvenile salmonids tend to congregate at the stream edges out of the thalweg. In Proposed Reach B, at the lower slopes, large wood will provide benefits to the stream system as well as provide habitat for amphibians, invertebrates, and birds in the form of perching, nesting, and feeding areas.

Wood Loading

The Fox and Bolton (2007) equation was used as a part of the WSDOT Large Woody Material metrics calculator spreadsheet to determine the 75th percentile target for number of wood pieces, key pieces, and wood volume based on the BFW and length of stream channel grading. The design targets for the 7.2- to 8.8-foot BFW channel are approximately 3 to 4 key pieces, 12 total wood pieces, and about 39.5 cubic yards of wood volume for every 100-foot length of stream. Based on the approximately 1,200-foot length of stream grading, the targets are40 key pieces, 139 total wood pieces, and a wood volume of 474 cubic yards. The design targets and proposed numbers and volume are shown in Table 46. Additional LWM calculations are shown in Appendix H.

LWM Type A are proposed as 24- to 36-inch diameter at breast height (DBH) with 30-foot minimum lengths. LWM Type B are proposed as 18- to 24-inch DBH with a minimum of 20 feet in length. LWM Type C are proposed as 12- to 18-inches DBH with a minimum of 15 feet in length.

The proposed design meets the target number of key pieces and large wood pieces. The large wood volume provided is about 205 cubic yards while the target is 474 cubic yards for the length of the crossing. The large wood is designed to function as habitat similar to the Upstream Reference Reach with scour pool formation and cover. Some additional logs are placed beyond the downstream end of the project to increase wood volumes, but the available area is limited by the Barleen Road embankment. Therefore, the target wood volume cannot be met due to the length of the culvert crossings and the lack of additional areas within the project area for wood to be incorporated. WSDOT does not allow placement of wood within culverts unless approved by HQ Hydraulics (WSDOT 2022a).

Table 46: Comparison of Large Wood Number and Volume in Design to Target Loading from Fox and Bolton (2007)

	No. of Key Pieces	No. of Large Wood Pieces	Large Wood Volume (cubic yards)
Target	40	139	473.8
Design	40	150	204.9

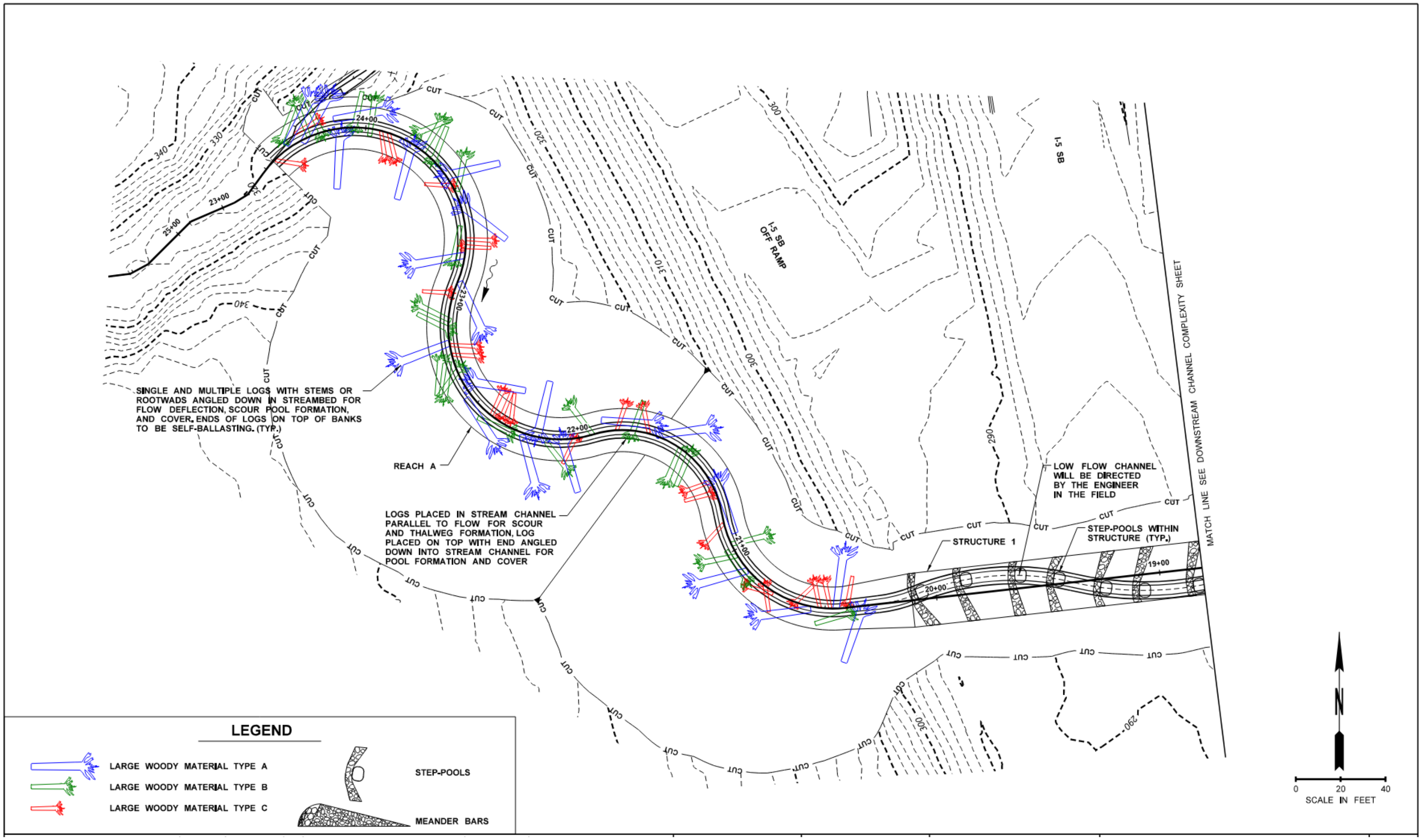


Figure 150: Conceptual Layout of Habitat Complexity Proposed Reach A (upstream)

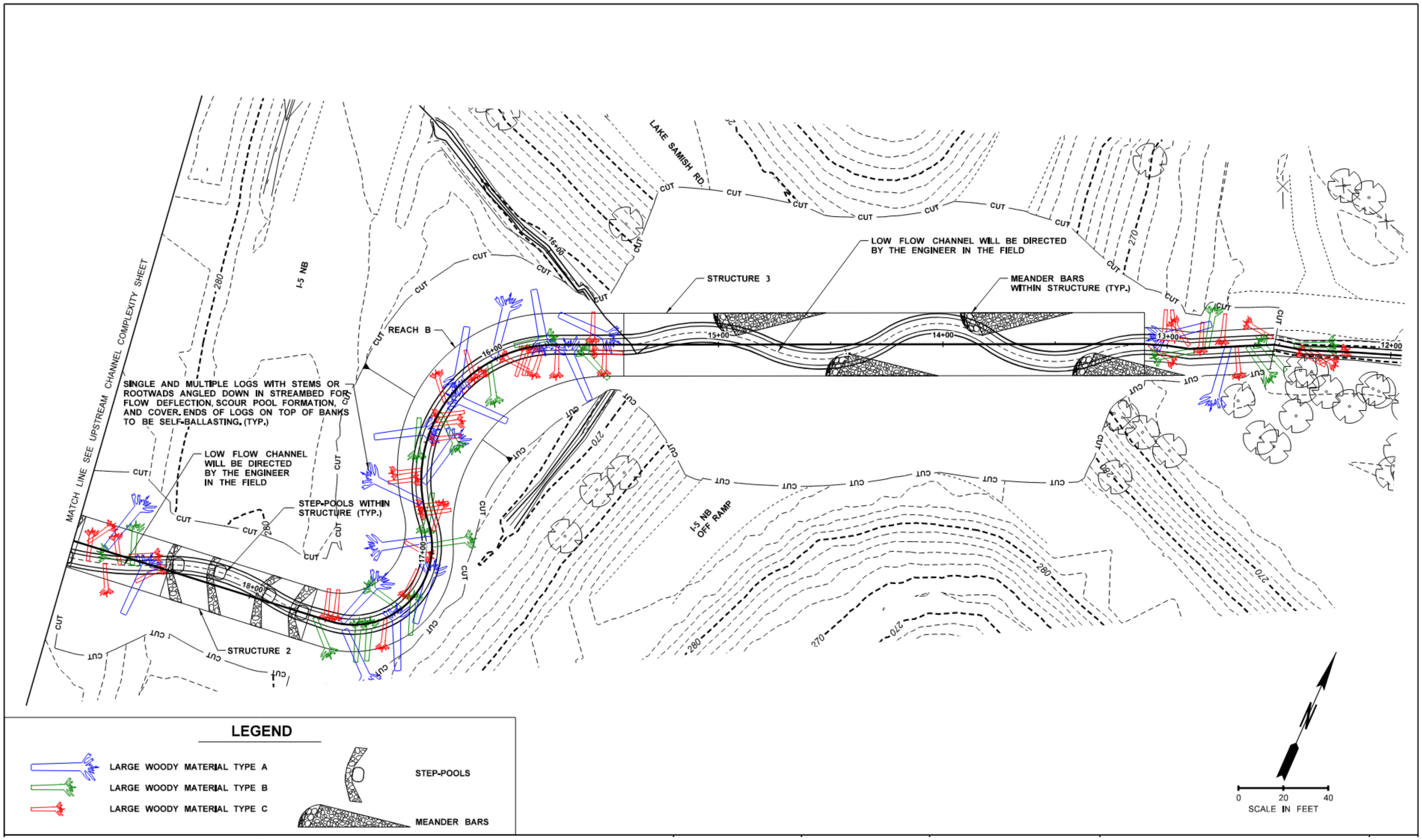


Figure 151: Conceptual Layout of Habitat Complexity Proposed Reach B (downstream)

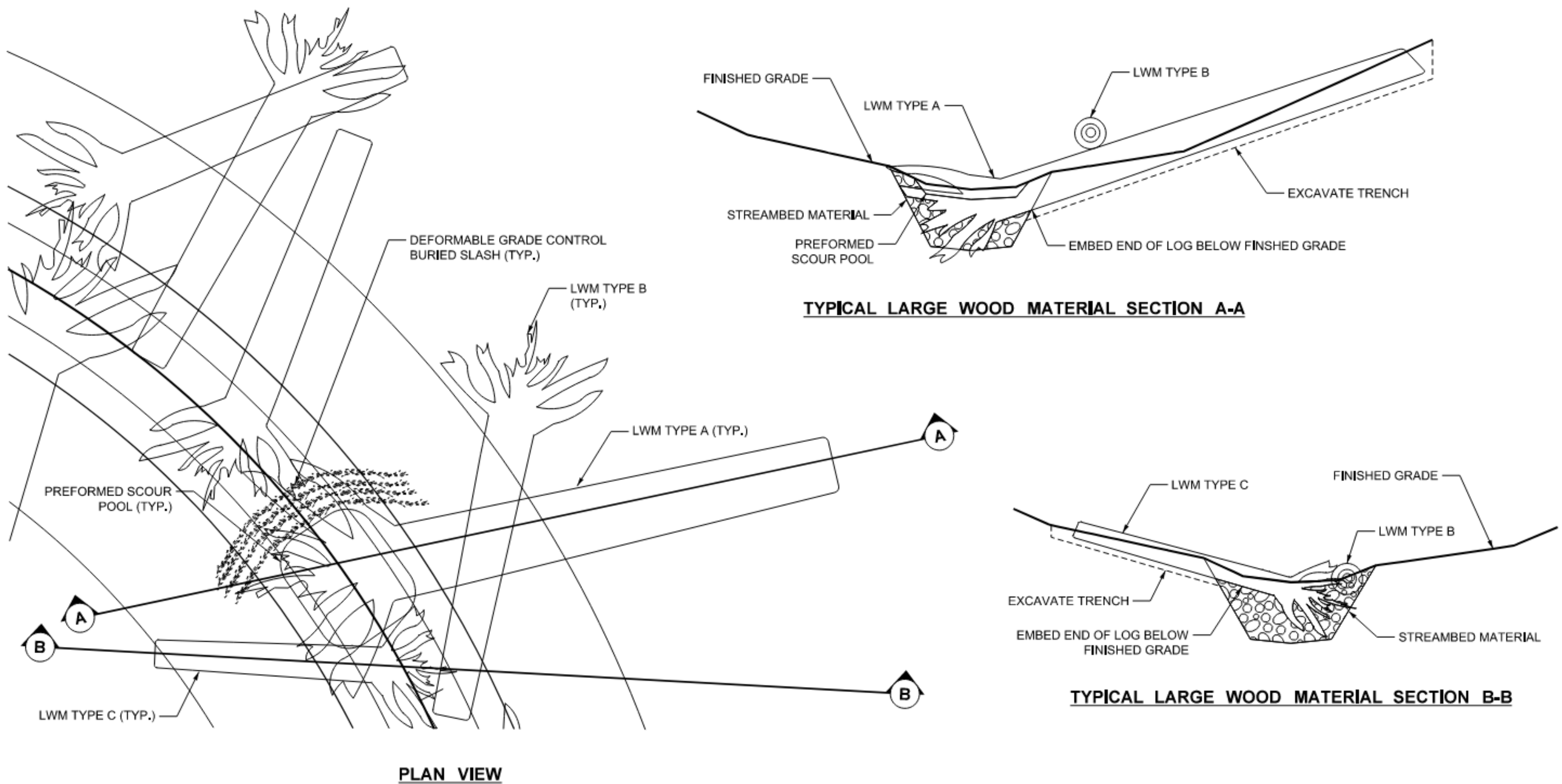


Figure 152: Typical Large Woody Material Placement Exhibit

5.2.2 *Additional Items for Further Design*

The design concept in this report is preliminary, and further design is required prior to construction. Some items that require additional evaluation for final design include, but are not limited to:

- Final step-pool dimensions, materials, and locations within culverts
- Final meander bar dimensions, materials, and locations within culverts
- Final large wood placement, deformable grade control design, and other habitat complexity features
- Scour depths within structures
- The existing inlet to the culvert near I-5 MP 240.86 is assumed to be abandoned in place. A drainage channel should be designed to direct flow from that culvert inlet to the Structure 1 inlet.
- The existing Culvert 995236 inlet is assumed to be abandoned in-place. The culvert inlet and abandoned channel immediately upstream should be evaluated to determin if runoff can be conveyed within the roadside ditch south to the Structure 1 inlet.
- The extents and potential modifications to the Barleen Road embankment will need to be evaluated during final design based on the transition from the Structure 3 outlet cross section to the downstream existing channel along Barleen Road.

6 Floodplain Changes

This project site is not within a FEMA-mapped floodplain. Downstream of the project site, at the South Tributary's confluence with Friday Creek, the floodplain is mapped as Zone A (Appendix A). The pre-project and expected post-project conditions were evaluated to determine whether there would be a change in WSE and floodplain storage.

6.1 Floodplain Storage

There is minimal floodplain storage provided by the existing culverts and stream channel within the project area under existing conditions. The stream channel is confined in the Upstream Reference Reach and, therefore, most flows will not engage the floodplain in Proposed Reach A. In Proposed Reach B, a riparian terrace has been designed upstream of Structure 3 that can be partially engaged during very high flows such as the 100-year peak flow. Structure 3 also allows high flows to engage the overbank within the 28-foot-wide minimum hydraulic opening and provides increased floodplain storage. Therefore, the proposed project will improve floodplain connectivity in Proposed Reach B from existing conditions. The project will not result in a reduction in floodplain storage.

6.2 Water Surface Elevations

The proposed project only results in local changes in WSEs due to addition of LWM to the stream that will increase roughness and flow depths for fish passage. The changes in WSEs will only occur within the project area and do not present any risk of flooding to properties or infrastructure. The proposed horizontal alignment differs substantially from the existing conditions alignment within the project area; therefore, the change in water surface profile would not provide a direct comparison. Downstream of the project and beyond the proposed LWM, the WSEs match existing conditions and do not represent a significant change from existing conditions.

Under existing conditions, flows that exceed the existing inlets of Culverts 995234 and 995232 due to sedimentation or large peak flows can overflow into the roadside ditches and flow north along I-5. Under the proposed conditions, all flows will be conveyed and sediment continuity will be restored downstream with the proposed new crossing structures. The project will increase flood storage and will reduce flow velocities within the project area. Large flows that are directed downstream will flow in the downstream channel adjacent to Barleen Road and, eventually, to the culvert under Barleen Road.

Restored sediment continuity from the proposed new crossings under I-5 has potential to result in sediment deposition in the downstream channel next to Barleen Road. If significant sediment deposition occurs, high flows would likely engage the forested area in the right overbank, creating a wetland. Under that condition, maintenance of the stream channel next to Barleen

Road could be needed, or the downstream culvert under Barleen Road could need to be replaced to restore sediment continuity farther downstream to the Friday Creek floodplain.

7 Climate Resilience

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. For bridges and buried structures, the largest risk to the structures will come from increases in flow and/or sea level rise. The goal of fish-passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

7.1 Climate Resilience Tools

WSDOT also evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the 2080 percent increase throughout the design of the structure. Appendix J contains the information received from WDFW for this site.

7.2 Hydrology

In addition to using the best available science for current site hydrology, WSDOT is evaluating the proposed structures at the 2080 predicted 100-year flow event to check for climate resiliency. The design flow for existing Culvert 995236 is 14.6 cfs at the 100-year flood event. The projected increase for the 100-year event in 2080 is 19.9 percent, yielding a 2080 projected 100-year flow rate of 17.5 cfs. The design flow for existing Culvert 995245 is 22.2 cfs at the 100-year flood event. The projected increase for the 100-year event in 2080 is 19.9 percent, yielding a 2080 projected 100-year flow rate of 26.6 cfs. The proposed stream realignment results in different hydrologic inputs at Structure 1 than at existing Culvert 995236. The design flow for proposed Structure 1 and proposed Structure 2 is 18.0 cfs. The 2080 projected 100-year flow rate for proposed Structure 1 and proposed Structure 2 is 21.6 cfs due to the 19.9 percent projected increase. As the proposed alignment and existing alignment converge upstream of Structure 3, the design flow and projected 2080 flow rates for Structure 3 are equal to the flow rates for existing Culvert 995245.

7.3 Climate Resilience Summary

The minimum hydraulic openings of 24 and 28 feet and the proposed vertical clearance allow for the channel to behave similarly through the proposed structures as it does in the adjacent reaches under the projected 2080 100-year flow event. This will help ensure that the structures are resilient to climate change and the system is allowed to function naturally, including the passage of sediment, debris, and water in the future.

8 Scour Analysis

Total scour will be computed during later phases of the project utilizing the 100-year, 500-year and projected 2080 100-year flow events. The structures will be designed to account for the potential scour at the projected 2080 100-year flow events.

For this phase of the project, the risk for lateral migration and potential for degradation/aggradation are evaluated below on a conceptual level. This information is considered preliminary and is not to be taken as a final recommendation in either case. Currently, geotechnical information is not available for the I-5 crossing, but it should be evaluated during later project phases prior to final design and how it may influence lateral migration and potential long-term degradation/aggradation. A supplemental scour memorandum will be prepared to provide more detailed scour analysis.

8.1 Lateral Migration

The potential for lateral channel migration exists with the proposed channel realignment upstream, at, and downstream of I-5.

Upstream of I-5, the proposed channel alignment (Proposed Reach A; Figure 124 and Figure 126) will have a slight meandering planform (sinuosity of 1.25), a steep slope (approximately 8.1 percent) and a step-pool morphology. The proposed reach is expected to function as a transport reach due to the steep slope. However, the placement of stable in-channel LWM will add channel roughness, reduce peak flow velocities, help stabilize the channel and banks, and promote localized deposition. Some channel migration may occur in Proposed Reach A as the stream responds to localized channel obstructions and depositional features; the LWM placement would help limit this risk. However, the highly entrenched nature of the stream due to its grading into the existing hillslope, combined with the limited expected overbank flow described in Section 4.6.1, will limit lateral migration that would occur through natural straightening of the meandering Proposed Reach A. In addition, the newly graded channel bed may be underlain by cohesive till, which is found throughout the Upstream Reference Reach and is generally resistant to erosion under the current flow regimes. Lateral migration upstream of I-5 will be further investigated at the FHD level in conjunction the potential minor alignment modifications described in Section 4.4.3.

At the I-5 crossing (Proposed Reach A and Structures 1 and 2), the stream will be conveyed through two structures, each with a minimum hydraulic opening of 24 feet. These structures will be constructed with stable step-pool features. The step-pools will be designed with boulders that would be stable up to the 100-year event. Over the lifetime of the project, the stream will have the potential to migrate within the structures, but migration would be limited by the structure’s width, which approximates the upstream valley width.

Downstream of I-5 (Proposed Reach B; Figure 124 and Figure 127), where the stream enters the Friday Creek valley, the proposed channel slope is lower. In this depositional reach, the potential for channel migration exists where sediment is deposited at and downstream of the channel gradient transition from higher upstream slopes to the lower valley slopes. The potential for channel migration in Proposed Reach B will be higher than in the upstream reaches (transport reaches). Similar to the design for Proposed Reach A, LWM will be placed throughout this reach to help provide overall channel and bank stability, which can help to limit the risk of channel migration. Also, banks consisting of established woody vegetation will help to limit the risk of bank erosion and lateral migration. Based on the surficial geology map for the area, the till layer may not be present along the stream's alignment in this reach. The valley bottom at Friday Creek is mapped as glaciomarine drift.

In the short term, after construction of the proposed new channel alignment, erosion control measures are recommended to help limit lateral bank erosion (horizontal stability) and are recommended to remain in place until the vegetation along the stream banks is established. In the long term, the channel banks and riparian corridor in Proposed Reaches A and B will consist of mature bank and canopy vegetation, including conifer trees, which will provide bank stability that will influence the rates and extents of lateral migration.

8.2 Long-Term Aggradation/Degradation of the Channel Bed

8.2.1 Existing Conditions

The existing channel consists of a steep reach upstream of I-5 (Reference Reach gradient of approximately 8.1 percent), an even steeper reach under/across I-5 (gradient of approximately 13 percent), and a flat reach downstream of I-5 (gradient of approximately 2.5 percent to 0.1 percent). Under existing conditions, sediment is transported out of the upper reaches (transport reaches) and sediment deposition occurs downstream in the flatter reach (depositional reach) near Culvert 995232 where the grade transitions from steep to flat. This has resulted in WSDOT removing accumulated sediment at the outlet to Culvert 995232, with the most recent removal in 2018 (Case, personal communication, April 21, 2021). Approximately 2 feet of sediment has accumulated in the channel at the outlet of Culvert 995232 (based on the diameter of the existing culvert) between 2018 and the January 2021 Site Visit. (Figure 20).

The vertical stability of the existing upstream reach is described in Section 2.8.4. The Upstream Reference Reach consists of step-pool morphology, and areas of incision were observed. This channel incision does not appear to be the result of widespread head cutting, but rather the result of the channel downcutting along its steep alignment.

Through the I-5 interchange (Project Reach) where the stream is conveyed through a series of culverts and open ditches, the stream grade is mostly controlled by the slopes of the culverts. Deposition was noted downstream of Culvert 995233 and 995232, where the culvert outlets (particularly 995232) are almost totally submerged with accumulated sediment.

8.2.2 Proposed Conditions

Due to the steep slopes through the transition from the hillside to the valley floor, there is potential for vertical adjustments of the realigned South Tributary profile if the stream channel is not adequately roughened with the placement of large and small wood to emulate the relative stability of the Upstream Reference Reach. The proposed wood placement will provide sediment retention and reduction in flow velocities within the open channel. In Structures 1 and 2, the proposed step-pool features will help retain and trap sediment as it is transported downstream. In addition, these step-pools will add roughness, reducing flow velocities and providing stability for the streambed within the proposed structures. The proposed meander bar and boulder clusters will add roughness and reduce flow velocities in Structure 3. The realigned stream channel provides additional clearance within the three structures, allowing sediment aggradation and reducing the risk of flooding the roadways or adjacent properties.

Temporary erosion control measures need to be installed along excavated side slopes (i.e., channel banks) to provide horizontal stability and reduce erosion immediately post-construction until bank and riparian vegetation establishes (outside of the structures).

8.2.3 Proposed Reach A

Upstream of I-5 (Proposed Reach A), where the channel regrade is designed with a grade of 8.1 percent, LWM is proposed throughout the channel and along the banks. As flows are introduced, the channel bed will undergo initial adjustments. Sediment will be mobilized and sorted based on localized hydraulic conditions in and around the placed LWM and large boulders. Along this steeper open open-channel segment of Proposed Reach A, initial degradation would be expected until the channel reaches equilibrium with the channel adjusting to its step-pool morphology, trending towards stable forms observed in the upstream reference reach. However, widespread reach-scale degradation is not expected based on stabilization and roughness in the channel design from LWM placement. In addition, a resistant till layer may be present that would help limit the rate and amount of degradation.

With the project, the proposed grade of the channel at the I-5/Lake Samish Road interchange would be less than the existing grade (approximately 13 percent); the steeper portion under I-5 is designed to have a maximum grade of approximately 6.3 percent. In Structures 1 and 2 under I-5, step-pools consisting of streambed boulders, cobbles, and buried slash are designed to provide stability, create roughness, and slow peak flow velocities. The step-pools will slow peak flow velocities, trap sediment, and prevent widespread erosion and degradation. Within the structures, initial localized degradation in the range of up to 1 foot would be expected until the channel reaches equilibrium. Between the upper and lower structures under I-5, LWM will be placed in the channel reach that is day-lighted between the two structures. This LWM placement will help to retain mobilized sediment exiting the upper structures.

Long-term degradation potential along Proposed Reach A, based on the curve of equilibrium presented in Section 2.8.4, Vertical Channel Stability, may be in the range of 10 feet (Figure 65). However, the LWM placement and the stable step-pool features (inside the structures) will provide overall bed stability and will potentially limit the amount of reach-scale degradation predicted by this curve over the lifespan of the project.

8.2.4 Proposed Reach B

Throughout Proposed Reach B, the potential for long-term aggradation exists as a result of the change in grade from the steeper, upstream Proposed Reach A to the lower gradient, downstream Proposed Reach B. Sediment transported from Proposed Reach A will deposit within the flatter Proposed Reach B slopes, which have been designed to occur within the median downstream of the I-5 northbound lanes. The proposed stream sediment sizing in Proposed Reach A is similar to the existing sediment in Upstream Reference Reach to meet stream simulation criteria. The stream section within Proposed Reach B allows sediment deposition and connection within the floodplain. The hydraulic modeling for the proposed conditions predicts lower shear stresses along Proposed Reach B than upstream of I-5. The calculated mobility for different cobble sizes based on slope and flow event is described in Section 5.1.3.

In Proposed Reach B, the stream flattens to a grade ranging from 3.2 to 1.7 percent. The proposed stream sediment gradation in this reach is a mobile bed design, where the D_{84} particle size would be mobile at a 2-year event (Table 42). Therefore, higher flows will have the potential to transport the accumulated sediment downstream. However, overall, channel aggradation would be expected in this reach with the increase in channel roughness provided by the LWM, localized areas of deposition at the LWM pieces, and the lower channel gradient.

Over the long term, the depositional area within Proposed Reach B and Structure 3 would likely adjust based on the incoming sediment supply with an increased stream grade. The stream grade would likely increase until the sediment transport capacity of the reach approaches the sediment supply based on the slope, to reach a relative equilibrium over the long term. Sediment from upstream may deposit with Proposed Reach B during a large flow event, and the deposited sediment would eventually move farther downstream when another large flow event occurs.

During higher flows, sediment could be transported downstream outside of the WSDOT project area (downstream of Culvert 995245) into the channel along Barleen Road, where slopes are in the range of 2.5 percent to 1.4 percent. The downstream private culvert under Barleen Road (931905) is a 36-inch-diameter concrete culvert and likely reduces the sediment transport capacity of the channel along Barleen Road. The estimated long-term potential sediment deposition is in the range of 2 feet in depth within the channel along Barleen Road, based on the bankfull depth and the downstream culvert.

The potential grade increase in the channel along Barleen Road would translate into an increased grade within Proposed Reach B based on the stream transport capacity approaching the upstream sediment supply over the long term. Based on the potential estimated 2 feet of sediment within the channel along Barleen Road, approximately 2 to 4 feet of potential sediment deposition is estimated within Structure 3 and Proposed Reach B over the long term.

Replacement of the downstream Culvert 931905 under Barleen Road would increase sediment transport capacity and reduce the estimated depth of sediment deposition within Proposed Reach B and the channel along Barleen Road.

9 Summary

Table 47 presents a summary of the results of this PHD Report.

Table 47: Report Summary Table

Stream Crossing Category	Elements	Values	Report Location
Habitat Gain	Total length	4,209 feet	1 Introduction 2.7.3.5 South Tributary Habitat Gains
Bankfull Width	Reference reach found?	Yes	2.8.1 Reference and Design Reach Selection
	Average BFW	7.8 feet upstream, 8.9 feet downstream	2.8.2 Channel Geometry
	Concurrence BFW	7.8 feet upstream	2.8.2 Channel Geometry
Channel Slope/Gradient	Existing crossing	13%	2.4 Site Description
	Reference Reach	8.1%	2.8.2 Channel Geometry
	Proposed	1.7%–8.1%	4.4.4 Channel Gradient
Countersink	Proposed	Minimum of 3 feet	4.7.3 Freeboard/ 8 Scour Analysis
	Added for climate resiliency	N/A	4.7.3 Freeboard/ 8 Scour Analysis
Scour	Analysis	TBD	8 Scour Analysis
	Streambank protection/stabilization	TBD	8 Scour Analysis
Channel Geometry	Existing	See Link	2.8.2 Channel Geometry
	Proposed	See Link	4.4.2 Channel Planform and Shape
Channel Conditions	Dry channel in summer	No	2.7.2 Existing Conditions
Floodplain Continuity	FEMA mapped floodplain	No	2.3 Floodplains
	Lateral migration	Yes, risk for channel migration.	2.8.5 Channel Migration
	Floodplain changes?	Yes, increased	6 Floodplain Changes
Freeboard	Required above 100-year	3.0 foot	4.7.3 Freeboard
	Added for climate resiliency	0.1 foot	4.7.3 Freeboard
	Additional recommended	5.0 feet	4.7.3 Freeboard
Maintenance Clearance	Proposed	4 feet to 6 feet, Increase to 6 feet or greater where feasible	4.7.3 Freeboard
Substrate	Existing	0.8 inch	2.8.3 Sediment
	Proposed	0.9 inch	5.1.3 Proposed Streambed Sediment Sizing
	Coarser than existing?	Yes; however, within 20%	5.1.3 Proposed Streambed Sediment Sizing

Stream Crossing Category	Elements	Values	Report Location
Hydraulic Opening	Proposed	Structure 1 – 24 feet, Structure 2 – 24 feet, Structure 3 – 28 feet	4.7.2 Minimum Hydraulic Opening Width and Length
	Added for climate resiliency	No	4.7.2 Minimum Hydraulic Opening Width and Length
Channel Complexity	LWM for bank stability	Yes	5.2.1 Design Concept
	LWM for habitat	Yes	5.2.1 Design Concept
	Step-pools	Yes	5.1.4 Step-Pools
	Meander bars	Yes	5.1.5 Meander Bars
	Boulder clusters	No	N/A
	Coarse bands	No	N/A
	Mobile wood	Yes	5.2.1 Design Concept
Crossing Length	Existing	Total of 630 feet	2.7.2 Existing Conditions
	Proposed	Structure 1 – 148 feet, Structure 2 – 66 feet, Structure 3 – 232 feet	4.7.2 Minimum Hydraulic Opening Width and Length
Floodplain Utilization Ratio (FUR)	Flood-prone width	Varies, 5.6 to 7.2 feet	4.4.1 Floodplain Utilization Ratio
	Average FUR upstream and downstream	1.4 upstream 1.5 downstream	4.4.1 Floodplain Utilization Ratio
Hydrology/Design Flows	Existing	2 year – 5.0 cfs 100-year – 16.5 cfs	3 Hydrology and Peak Flow Estimates
	Climate resiliency	2080 100-year – 22.2 cfs	7.2 Hydrology
Channel Morphology	Existing	Step-pool upstream Plane-bed downstream	2.8.2 Channel Geometry
	Proposed	Reach A – step-pool Reach B – step-pool and pool-riffle	4.4.4 Channel Gradient
Channel Degradation	Potential?	Yes	8.2 Long-Term Aggradation/Degradation of the Channel Bed
	Allowed?	Yes	8.2 Long-Term Aggradation/Degradation of the Channel Bed
Structure Type	Recommendation	No	4.7.1 Structure Type
	Type	TBD	4.7.1 Structure Type

Note: N/A = not applicable; TBD = to be determined

10 References

Aquaveo. 2021. Surface Water Modeling System (SMS) User Manual, SMS Version 13.1.12. https://www.xmswiki.com/wiki/SMS:SMS_User_Manual_13.0#The_Surface-water_Modeling_System. Accessed 11/3/2021.

Arcement, G.J., and V.R. Schneider. 1989. Guide for selecting Manning's roughness coefficients for natural channels and floodplains. USGS Water Supply Paper 2339. Available at: Guide for selecting Manning's roughness coefficients for natural channels and flood plains (usgs.gov).

Barnard, R.J., J. Johnson, P. Brooks, K.M. Bates, B. Heiner, J.P. Klavas, D.C. Ponder, P.D. Smith, and P.D. Powers. 2013. *Water Crossing Design Guidelines*. Washington Department of Fish and Wildlife. Olympia, Washington.

Brown, S.A., J.D. Schall, J.L. Morris, C.L. Doherty, S.M. Stein, and J.C. Warner. 2009. Hydraulic Engineering Circular No. 22 (HEC-22): *Urban Drainage Design Manual*. Third Edition. Publication FHWA-NHI-10-009. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. September 2009 (Revised August 2013).

Case, Jon. 2021. Personal communication with Clint Terwilliger (WSDOT), email dated April 21, 2021.

Chow, V.T. 1959. *Open Channel Hydraulics*. New York: McGraw-Hill Book Company.

Cluer, B., and C. Thorne. 2014. A Stream Evolution Model Integrating Habitat and Ecosystem Benefits. *River Research and Applications* 30: 134-154 (2014).

FEMA (Federal Emergency Management Agency) 1985. National Flood Insurance Program Flood Rate Insurance Map for Skagit County, Washington (Unincorporated Areas), Panel 50 of 550. Community-Panel Number 530151 0050 C. Effective January 3, 1985.

FHWA (Federal Highway Administration). 2019. *Two-Dimensional Hydraulic Modeling for Highways in the River Environment*. Publication No. FHWA-HIF-19-061. U.S. Department of Transportation. October 2019. Available at: https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif19061.pdf.

Kalisz, Glen. 2021. Personal communication with Jeff Gray (Otak), email dated November 1, 2021.

Lapen, T.J. 2000. Geologic Map of the Bellingham 1:100,000-scale quadrangle, Washington. Washington Division of Geology and Earth Resources. Open File Report 00-5p., 2 plates. Olympia, Washington.

Mastin, M.C., C.P. Konrad, A.G. Veilleux, and A.E. Tecca. 2016. *Magnitude, Frequency, and Trends of Floods at Gaged and Ungaged Sites in Washington, Based on Data through Water Year 2014* (ver 1.2, November 2017). U.S. Geological Survey Scientific Investigations Report 2016-5118. Available at: http://dx.doi.org/10.3133/sir20165118.

Montgomery, D and J. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin, May, 1997.

Montgomery, D. and J. Buffington. 1993. Channel Classification, Prediction of Channel Response, and Assessment of Channel Condition. Prepared for SHAMW committee of the Washington State Timber, Fish and Wild-Life. Dated June 24, 1993. Publication No.: TSW-SH10-93-002.

NRCS (National Resources Conservation Service). 2007. National Part 654 Stream Restoration Design, National Engineering Handbook: Chapter 12 Channel Alignment and Variability Design. Available at: https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17772.wba.

NRCS. 2020. Web Soil Survey. U.S. Department of Agriculture. Available at: http://websoilsurvey.sc.egov.usda.gov/.

PRISM Climate Group. 2022. 30-Year Normal Precipitation: Annual. Oregon State University, Northwest Alliance for Computational Science and Engineering. Available at: http://www.prism.oregonstate.edu/normals/.

Smith, C.J. 2003. Salmon and steelhead habitat limiting factors Water Resource Inventory Areas 3 & 4 Skagit Watershed. Washington State Conservation Commission, Olympia, Washington.

USDA (United States Department of Agriculture). 2008. *Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings*. USDA Forest Service Stream-Simulation Working Group, National Technology and Development Program. San Dimas, California.

USDA. 2018. Flow Resistance Coefficient Selection in Natural Channels: A Spreadsheet Tool. Technical Summary TS-103.2. USDA Forest Service.

USDA. 2014. Photographic Guidance for Selecting Flow Resistance Coefficients in High-Gradient Channels. General Technical Report RMRS-GTR-323. USDA Forest Service.

USGS (United States Geological Survey). 2016. The StreamStats program, online at http://streamstats.usgs.gov, accessed on June 27, 2019.

USGS. 2017. Western Washington 3DEP LiDAR Technical Data Report, Contract No. G16PC00016, Task Order No. G16PD00383.

USGS. 2020. USGS one meter x54y539 WA Western North 2017 – LiDAR.USBR (United States Department of the Interior, Bureau of Reclamation). 2017. SRH-2D Version 3.2.4.

Washington Department of Fish and Wildlife (WDFW). 2011a. WDFW Fish Passage and Diversion Screening Inventory Database Site Description Report and Level A Culvert Assessment Report for Unnamed Tributary to Friday Creek (Site ID 995245) at I-5; NB off-ramp, MP 240.92. Unpublished.

WDFW. 2011b. WDFW Fish Passage and Diversion Screening Inventory Database Site Description Report for Unnamed Tributary to Friday Creek (Site ID 931904) at Unnamed Road (upstream of the project). Unpublished.

WDFW) 2011c. WDFW Fish Passage and Diversion Screening Inventory Database Site Description Report for Unnamed Tributary to Friday Creek (Site ID 931905) at Barleen Road. Unpublished.

WDFW. 2011d. WDFW Fish Passage and Diversion Screening Inventory Database Site Description Report and Level A Culvert Assessment Report for Unnamed Tributary to Friday Creek (Site ID 995236) at I-5; SB Ext 240, MP 240.92. Unpublished.

WDFW. 2011e. WDFW Fish Passage and Diversion Screening Inventory Database Site Description Report and Level A Culvert Assessment Report for Unnamed Tributary to Friday Creek (Site ID 995235) at I-5; SB ROW, MP 240.95. Unpublished.

WDFW. 2011f. WDFW Fish Passage and Diversion Screening Inventory Database Site Description Report and Level A Culvert Assessment Report for Unnamed Tributary to Friday Creek (Site ID 995234) at I-5; SB, MP 240.95. Unpublished.

WDFW. 2011g. WDFW Fish Passage and Diversion Screening Inventory Database Site Description Report and Level A Culvert Assessment Report for Unnamed Tributary to Friday Creek (Site ID 995233) at I-5; Median, MP 240.95. Unpublished.

WDFW. 2011h. WDFW Fish Passage and Diversion Screening Inventory Database Site Description Report and Level A Culvert Assessment Report for Unnamed Tributary to Friday Creek (Site ID 995232) at I-5; NB, MP 240.95. Unpublished.

WDFW. 2019. *Fish Passage and Surface Water Diversion Screening Assessment and Prioritization Manual*. Olympia, Washington. Available at: Fish Passage Barrier and Surface Water Diversion Screening Assessment and Prioritization Manual | Washington Department of Fish & Wildlife.

WDFW. 2020a. Statewide Washington Integrated Fish Database (SWIFD) Web Map. Available at https://geo.nwifc.org/swifd/.

WDFW. 2020b. Habitat Program, Fish Passage Division. Fish Passage and Diversion Screening Inventory (FPDSI). Available at https://geodataservices.wdfw.wa.gov/hp/fishpassage/index.html.

WSDOT. 2019. Protections and Connections for High Quality Natural Habitats. Secretary's Executive Order Number: E1031.02. April 1, 2019.

WSDOT. 2021a. WSDOT Culvert Inspection Report (Site Id: 995236). January 19, 2021. Unpublished.

WSDOT. 2021b. WSDOT Culvert Inspection Report (Site Id: 995235). January 19, 2021. Unpublished.

WSDOT. 2021c. WSDOT Culvert Inspection Report (Site Id: 995234). January 19, 2021. Unpublished.

WSDOT. 2021d. WSDOT Culvert Inspection Report (Site Id: 995233). January 19, 2021. Unpublished.

WSDOT. 2021e. WSDOT Culvert Inspection Report (Site Id: 995232). January 19, 2021. Unpublished.

WSDOT. 2021f. WSDOT Culvert Inspection Report (Site Id: 995245). January 19, 2021. Unpublished.

WSDOT. 2022a. *Hydraulics Manual*. Olympia, WA. Publication Number M 23-03.07. March 1, 2022.

WSDOT. 2022b. Meander Bars for Water Crossing Structures in Stream Simulation, Design Considerations for Success. April 2022.

WSDOT. 2022c. I-5 UNT to Friday Cr – Geotechnical Scoping Package. July 2022.

Yochum, S.E., B.P. Bledsoe, G.C.L. David, and E. Wohl. 2012. Velocity Prediction in High-Gradient Channels. *Journal of Hydrology*. 424-425 (March 6, 2012): 84-98. http://dx.doi.org/10.1016/j.jhydrol.2011.12.031.

11 Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: SRH-2D Model Results

Appendix D: Streambed Material Sizing Calculations

Appendix E: Stream Plan Sheets, Profile, and Details

Appendix F: Scour Calculations

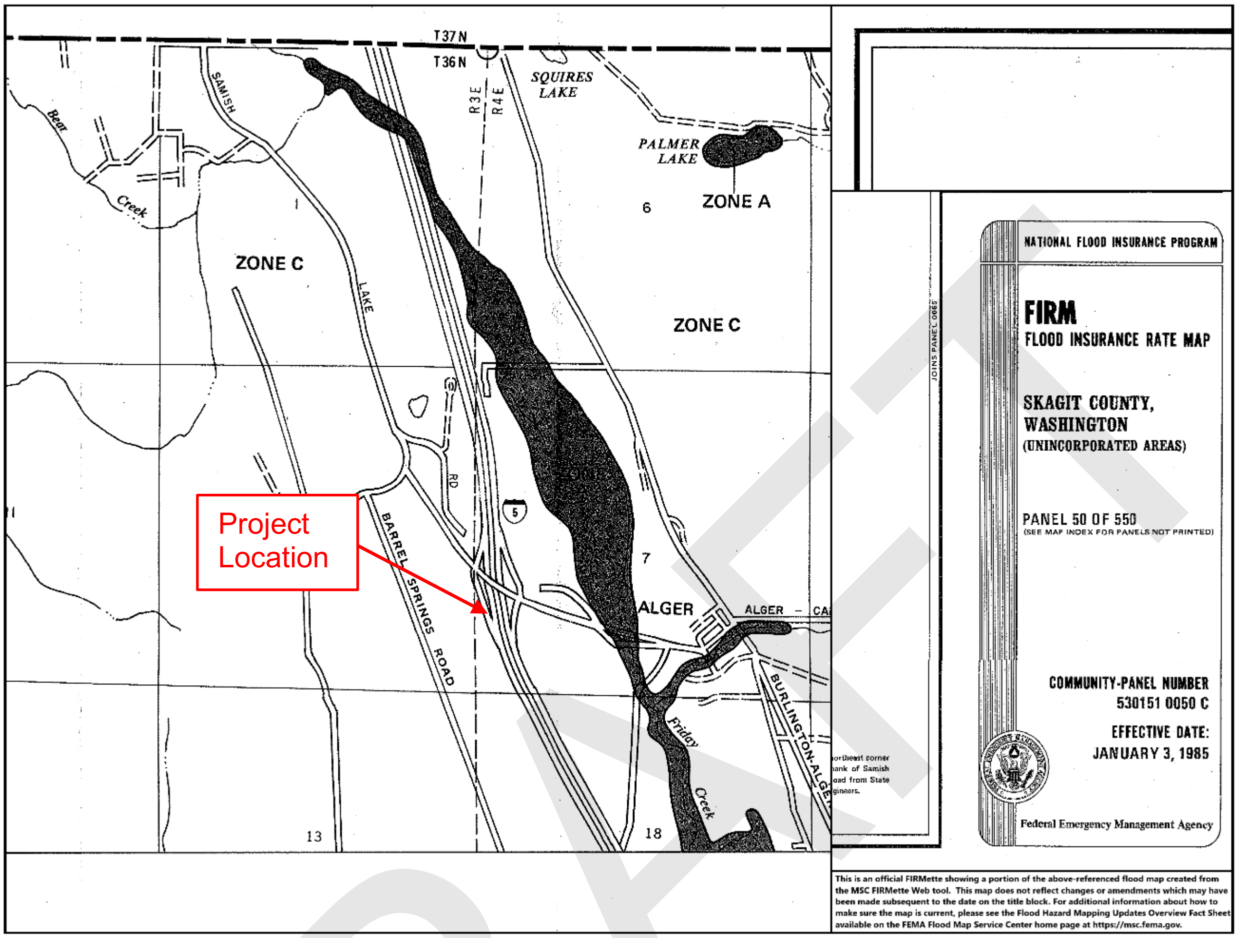
Appendix G: Manning's Calculations

Appendix H: Large Woody Material Calculations

Appendix I: Reach Assessment

Appendix J: Climate Resiliency Calculations

Appendix A: FEMA Floodplain Map


T37N
T36N
R3E
R4E
SQUIRES LAKE
PALMER LAKE
ZONE A
6
ZONE C
Bear Creek
SAMISH
LAKE
RD
ZONE C
1
Project Location
BARREL SPRINGS ROAD
5
7
ALGER
ALGER — CA
BURLINGTON-ALGER
Friday Creek
13
18
JOINS PANEL 0065
NATIONAL FLOOD INSURANCE PROGRAM
FIRM
FLOOD INSURANCE RATE MAP
SKAGIT COUNTY, WASHINGTON
(UNINCORPORATED AREAS)
PANEL 50 OF 550
(SEE MAP INDEX FOR PANELS NOT PRINTED)
COMMUNITY-PANEL NUMBER
530151 0050 C
EFFECTIVE DATE:
JANUARY 3, 1985
Federal Emergency Management Agency
This is an official FIRMette showing a portion of the above-referenced flood map created from the MSC FIRMette Web tool. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For additional information about how to make sure the map is current, please see the Flood Hazard Mapping Updates Overview Fact Sheet available on the FEMA Flood Map Service Center home page at https://msc.fema.gov.

Appendix B: Hydraulic Field Report Form

WSDOT Hydraulics Section	Hydraulics Field Report	Project Number: 995236, 995235, 995234, 995233, 995232, 995245
	Project Name: Unnamed Tributary to Friday Creek	Date: 01/27/2021
	Project Office: Northwest Office	Time of Arrival: 8:30 AM
	Stream Name: South Tributary	Time of Departure: 2:20 PM
WDFW ID Number: 995236, 995235, 995234, 995233, 995232, 995245	Purpose of Site Visit: Stream Reconnaissance	Prepared By: Dave Stewart, Teddy Thorson
State Route/MP: I-5, MP 240	Weather: Light Rain	

Meeting Location:
Alger, Skagit County, WA

Attendance List:

Name	Organization	Role
Dave Stewart	Otak, Inc.	Stream Design Engineer
Jamie Bails	Otak, Inc.	Habitat Biologist
Teddy Thorson	Otak, Inc.	Water Resources Designer
Tyson Hounsel	Otak, Inc.	Stream Design Engineer

Otak conducted a site visit on January 27, 2021 to assess the stream conditions of the south unnamed tributary to Friday Creek (South Tributary) at the location where Lake Samish Road crosses Interstate 5 (I-5) at exit 240. Data collected by Otak during the site visit included 12 bankfull width and depth measurements and five pebble counts.

Bankfull Width:

Otak, Inc. conducted a field-based geomorphic assessment and stream reconnaissance to South Tributary to Friday Creek crossing at approximately Mile Post (MP) 241 on I-5 on January 27, 2021 (**Figure 1**). As part of the geomorphic assessment, bankfull width (BFW) measurements and pebble counts were collected within the project site. Otak collected a total of 12 BFW measurements, including eight bankfull measurements upstream of WDFW crossing 995236 (the upstream reach), one bankfull measurement between crossings 995245 and 995232 (the project reach) and three bankfull measurements downstream of crossing 995245 (the downstream reach). BFW measurement locations are shown in **Figure 2,** results summarized in **Table 1**, and photo documentation provided at the end of this form.

The upstream reach was determined to be a reference reach for the natural stream conditions due to the influence of the I-5 corridor on the downstream reaches. The eight bankfull width measurements within the reference reach were used to determine an average bankfull width of 7.8 feet for the tributary based on field measurements. The bankfull width of the stream was variable due to the influence of large wood including large root wads, cascades, pools, and other natural features. BFW measurements were generally taken outside the influence of these features. Bankfull width measurements below 995236 are not considered representative of a natural stream due to the influence of I-5 and were not used for determining the average bankfull width calculation.

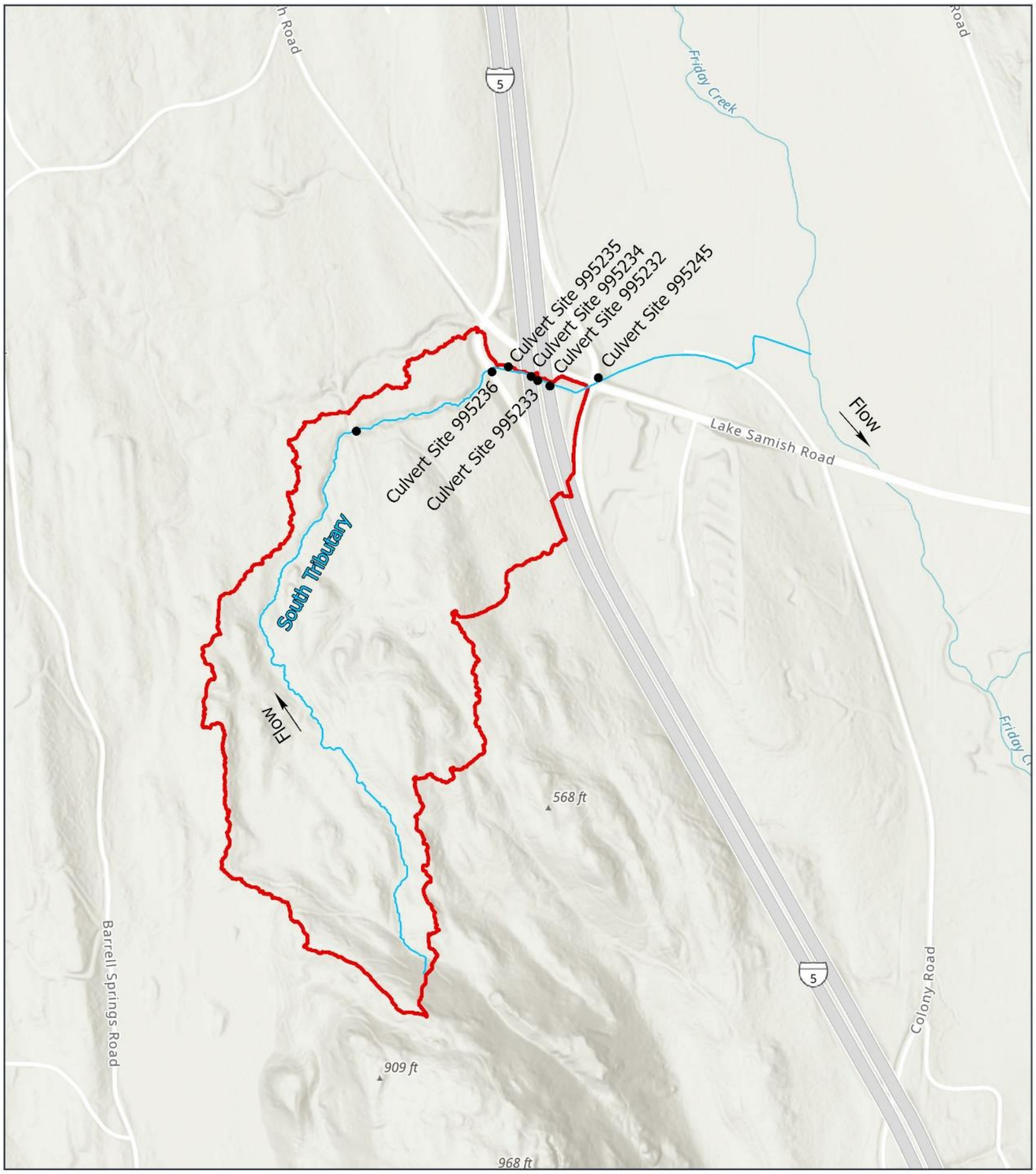


FIGURE 1

SOUTH UNNAMED TRIBUTARY TO FRIDAY CREEK DRAINAGE BASIN MAP

ALGER, WA

- WDFW Fish Passage Site
- South Unnamed Tributary to Friday Creek
- Drainage Basin

0 800 feet

NOTE: THIS DATA IS NOT TO SURVEY ACCURACY AND IS MEANT FOR PLANNING PURPOSES ONLY.
DATE: 3/2/2021
Y:\SHARED\PROJECTS\WSDOT\WSDOT GEC FISH PASSAGE\50 CADD\51 GIS\APRX\SOUTH_TRIB_FIG_1.APRX

HNTB WSDOT Otak

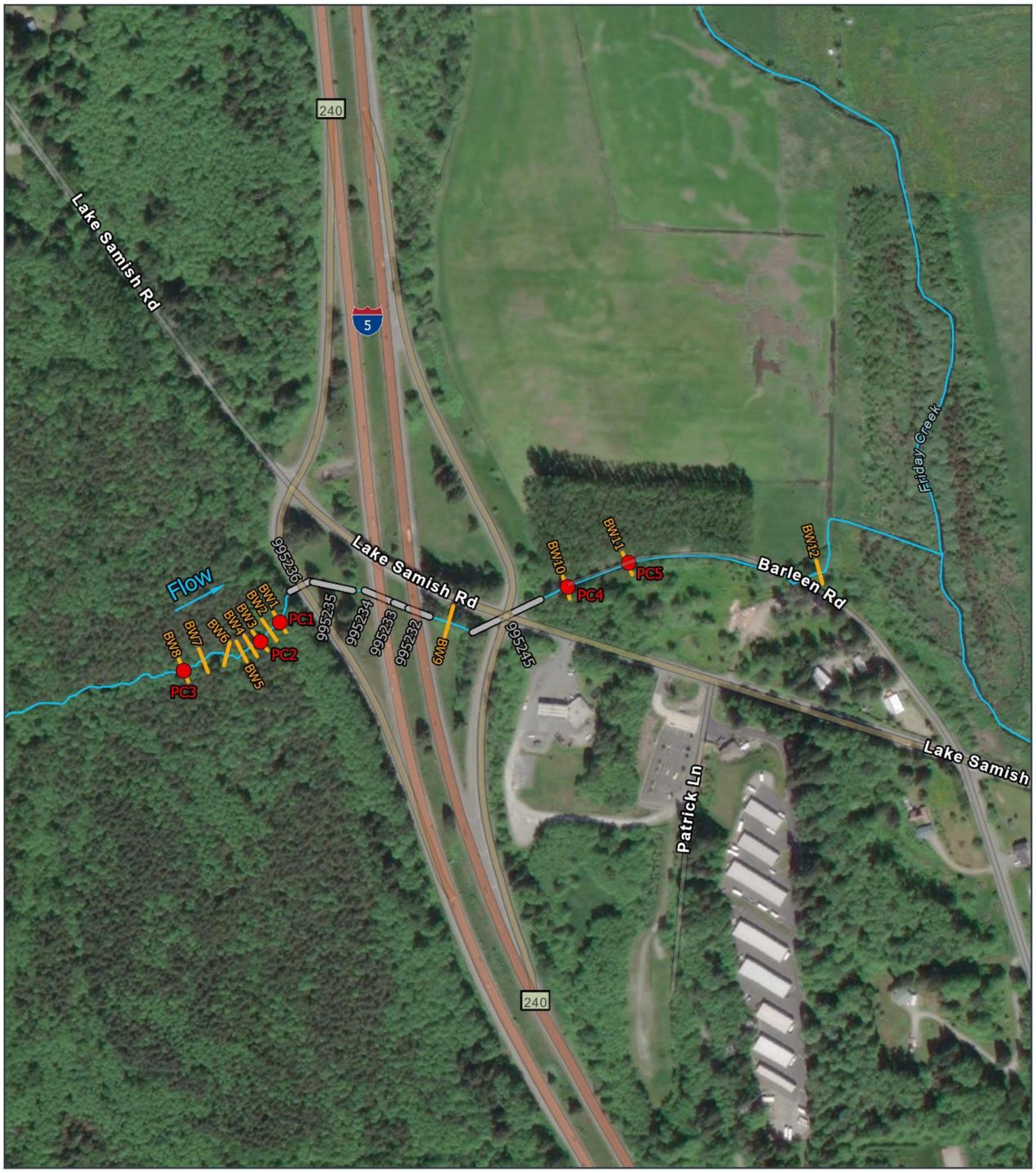


FIGURE 2

SOUTH UNNAMED TRIBUTARY TO FRIDAY CREEK FIELD MEASUREMENTS

ALGER, WA

Stream
Culverts
Pebble Count (PC)
Bankfull Width (BW)

feet
0 400

NOTE: THIS DATA IS NOT TO SURVEY ACCURACY AND IS MEANT FOR PLANNING PURPOSES ONLY.
DATE: 2/23/2021
Y:\SHARED\PROJECTS\WSDOT\WSDOT GEC FISH PASSAGE\50 CADD\51 GIS\APRX\SOUTHERN_TRIB_AERIAL.APRX

Table 1. Summary of bankfull measurements.

Number	Bankfull Width (ft)	Bankfull Depth (ft)	US or DS of crossing	Crossing	Reach Name	Approximate distance from culvert (ft)	Pebble Count/ Sediment Sample?
BW1	9.6	2.8	US	995236	Upstream	104	No
BW2	8.3	2.1	US	995236	Upstream	164	Yes
BW3	8.3	1.6	US	995236	Upstream	225	No
BW4	7.5	1.7	US	995236	Upstream	256	No
BW5	7.9	1.2	US	995236	Upstream	288	Yes
BW6	8.7	1.4	US	995236	Upstream	319	No
BW7	6.5	1.4	US	995236	Upstream	397	No
BW8	5.7	1.7	US	995236	Upstream	475	Yes
BW9*	7.3	1.5	US	995245	Project	50	No
BW10*	8.5	3	DS	995245	Downstream	79	Yes
BW11*	9.3	2.5	DS	995245	Downstream	265	Yes
BW12*	10.0	1.5	DS	995245	Downstream	1,104	No

**Note: BW9 – BW12 are not considered representative of the reference reach, and were not used in the calculation of average bankfull width.*

Reference Reach:

Otak evaluated the upstream reach for the South Tributary to Friday Creek and measured bankfull widths from approximately 104 feet upstream of crossing 995236 (BW1) and continuing to approximately 475 feet upstream of crossing 995236 (BW8). This reach was selected as the best reference reach for the tributary because it is upstream of the culvert crossings under I-5, has relatively stable channel morphology, and potential healthy fish habitat in its current state. The first 30 feet of the stream upstream of crossing 995236 contains several boulder steps or drops that appear to have been intentionally placed, and therefore measurements were taken starting approximately 100 feet upstream of the culvert (995236).

The upstream reach planform consists of a single-thread channel flowing within a confined, moderately steep valley. The reach generally consists of a step-pool and forced step-pool morphology with gravel, cobble and boulder riffles. Segments of the stream banks are undercut along the reach from bank toe erosion. Exposed tree roots and large wood debris appear to provide some lateral stability. Small and large woody debris is abundant, and in places the woody material appears to have stabilized the channel banks from further erosion. Several large trees have been undercut by erosion and fallen over with the rootwads and soil extending mid-channel. Also, large wood has fallen into the stream and riparian areas from the steep valley walls. The canopy cover for the reach was estimated as 85% with species consisting of Douglas fir, cedar, western hemlock and alder. The streambed material consists of sand, fine to coarse gravels, and cobbles, with low embeddedness. The bankfull widths varied from 9.6 feet to 5.7 feet, with an average of 7.8 feet.

There is a culvert approximately 800’ upstream of the 995236 culvert at an access /logging road, which has been identified by WDFW as a fish barrier (WDFW ID# 931904). Historical aerial images show that the logging road was constructed around 1976 and the basin was logged between 1976 and

1981. Based on the observed reference reach conditions, this culvert is considered to be far enough upstream that it is not significantly affecting the reference reach downstream due to the distance.
Data Collection:
Otak performed site visits to the South Tributary of Friday Creek from upstream of crossing 995236 to downstream of crossing 995245. Geomorphic data collection and assessments of the upstream, project, and downstream reaches were completed during the site visit including bankfull measurements, observations of channel morphology and stability, bed substrate, vegetative conditions, instream woody debris, and areas of aggradation and degradation. Otak took 12 measurements of bankfull width and five pebble counts and substrate observations across the three reaches.
Observations:

Site Layout

Otak is assigned to correct the fish barriers between crossings from 995236 (upstream) to 995245 (downstream). There are six culverts that have been identified by WSDOT as fish barriers between the upstream and downstream reaches. Three of the culverts are full fish barriers while the other three are partial fish barriers according to the Washington State Fish Passage Inventory data.

From the upstream reach, the South Tributary flows through the first five culverts with the stream daylighting for only several feet between each culvert inlet and outlet. The culvert crossing at 995236 is a 2-foot diameter culvert under the southbound I-5 on-ramp. The 995235 culvert crossing is a 2-foot diameter culvert under an embankment in the median between the on-ramp and the southbound lanes of I-5. The 995234 crossing is a 2-foot diameter culvert under the I-5 southbound lanes. The 995233 culvert is a 2-foot diameter culvert under the embankment median between the I-5 southbound and northbound lanes. The 995232 culvert crossing is a 2-foot diameter culvert under the I-5 northbound lanes, with significant embedment of sand at the culvert outlet.

The South Tributary to Friday Creek then flows in a modified channel for a length of about approximately 160 feet along the embankment for the Lake Samish Road overpass, to the 995245 culvert crossing. The 995245 culvert crossing consists of a 2.5-foot diameter culvert crossing diagonally under the intersection of the I-5 northbound on/off-ramp and Lake Samish Road. This crossing is listed as a total barrier due to the perched culvert condition at the downstream end. The drop from the downstream culvert end to the bottom of the scour hole that has formed was measured as about 4 feet.

Upstream Reach (Reference Reach)

About three boulder steps appear to have been placed across the stream channel within 30 feet upstream of the 995236 culvert. Upstream of the boulders and outside of the influence of the culvert, the stream channel appears to have a natural condition that is heavily dominated by large woody material. This upstream area is therefore considered to be the best candidate for the reference reach due to its lack of recent anthropogenic alterations and forested conditions.

The South Tributary in the upstream reach has a moderately high gradient (approximately 7 to 8%) with limited meandering. The stream morphology consists of step pool and forced step pool morphology with some areas of gravel, cobble and boulder riffles. Small pools are associated with the step pools.

The first bankfull width measurement (BW1) was taken about 100 feet upstream, and the farthest bankfull width measurement was taken at BW8, approximately 475 feet upstream of the 995236 culvert. The channel and its banks were observed to be eroded and undercut at multiple locations within the reach, with the channel moderately entrenched. However, the reach appears to be relatively stable as the wood and trees adjacent to the channel are holding the channel together and preventing significant channel widening and down cutting.

Abundant small and large woody debris was observed for the entire length of the reach. The wood material is supplied by fallen trees from the adjacent bank, riparian and forested valley slopes. The large wood material ranged from small branches to up to approximately 24" diameter logs, including several large trees with rootwads about six feet in diameter that have recently fallen. No beaver activity was observed in the reference reach. Not all recruited wood is engaged with the stream flows. The large wood that is within the stream channel, interacts and influences the morphology of the channel. There are abundant mature trees on the overbank larger than 18". The canopy coverage was estimated to be approximately 85%, and historical imagery showed that the area surrounding the upstream reach had been clear cut approximately 40 years ago. It appears conifers were replanted and trees have reestablished to at least 40 feet in height since the area was previously cleared.

Approximately 800 feet upstream of the 995236 crossing, a logging road with a 3-foot diameter culvert that has been identified as a WDFW fish passage barrier (ID# 931904). Based on the historical aerial photos, a logging road was in-place in 1976 and the upstream parts of the basin were logged between 1976 and 1981. Observations indicate the upstream culvert does not significantly affect the channel morphology in this reach due to the distance upstream.

The bed substrate was assessed to be fine to coarse gravels, with cobbles and boulders, with very low embeddedness. Three pebble counts and subsurface samples were collected in the upstream reach by Otak. There were increasing amounts of cobbles and boulders within the streambed with increasing distance upstream. Sporadic large boulders are present in the reach and measure up to approximately 24-inches in diameter and in some cases are associated with the step pools.

Downstream Reach

The downstream reach begins at the outlet of the 2-foot diameter culvert crossing 995245. A scour pool has formed at culvert outlet, with a measured pool depth of 2.8 feet below the water surface.

Downstream of culvert 995245, the stream flows east in a channelized stream parallel to Barleen Road, a gravel access road. The access road embankment forms the left channel bank, and the right overbank is forested. The channel has been straightened and modified over time. The stream channel banks are eroded, and the channel is entrenched and does not appear to access the floodplain over the left or right bank. The stream appears to be within an arrested state of degradation within this reach, with vegetation and trees on the right bank preventing further erosion. No vegetation is present on the left bank due to the access road. The riparian area in the right overbank is approximately ten times the bankfull width, and the canopy cover was estimated at approximately 80%. Small wood debris has accumulated within the channel from the adjacent forested area, and the small wood debris jams have created riffle-pool bedforms within the reach.

The streambed is scoured out to a till soil material near the culvert 995245 outlet, and the streambed material consists of sand, fine to coarse gravel, and a few cobbles downstream. The streambed gravel is significantly embedded by sand within the downstream reach.

Approximately 900 feet downstream of culvert 995245, the stream flows through a 3.5-foot diameter culvert (WDFW # 931905) that crosses under Barleen Road to the northeast. The South Tributary flows over an installed log weir on the downstream side of the culvert to the confluence with Friday Creek. The furthest downstream bankfull width (BFW 12) was measured as 10.0 feet downstream within this area for comparison.

Pebble Counts/Sediment Sampling:

Three pebble counts and substrate observations were taken in the upstream reach, and two pebble counts and substrate observations were taken for the downstream reach. Each pebble count and substrate observation was taken at the approximate location of a bankfull width measurement. A gravelometer and the standard Wolman Pebble Count procedure using the zig-zag method was used for each surface pebble count. The upstream reach has an average D50 and D84 of 21.5 mm and 55.3 mm, respectively. The downstream reach has an average D50 and D85 of 11.6 mm and 29.6 mm, respectively. No pebble counts were taken in the project reach because of the influence of the upstream and downstream culverts on the bed substrate. The gradations of the pebble counts are shown in Figures 3 – 12.

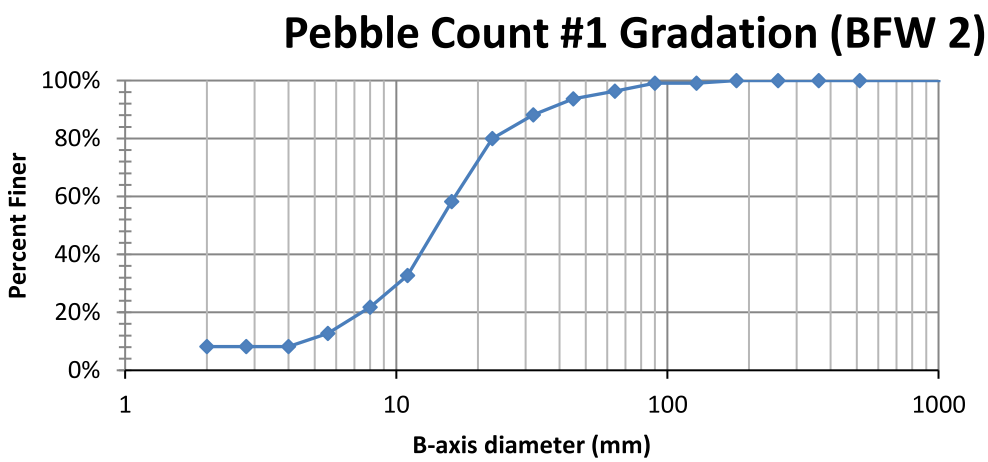


Figure 3. Pebble count #1 gradation at bankfull width measurement 2 in the upstream reach.

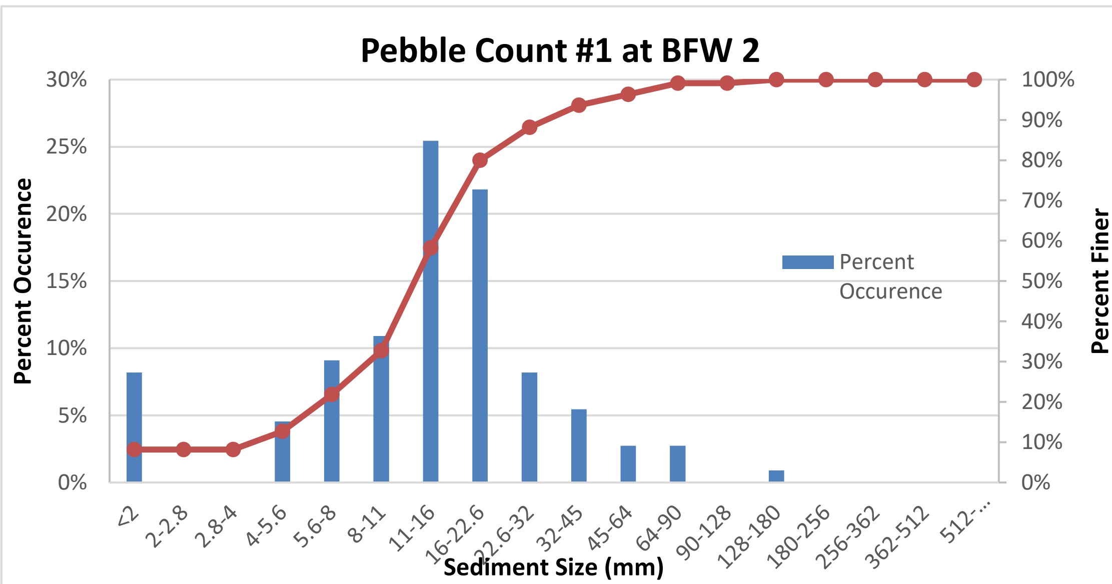


Figure 4. Percent occurrence by sediment size for the pebble count at bankfull width measurement 2 in the upstream reach

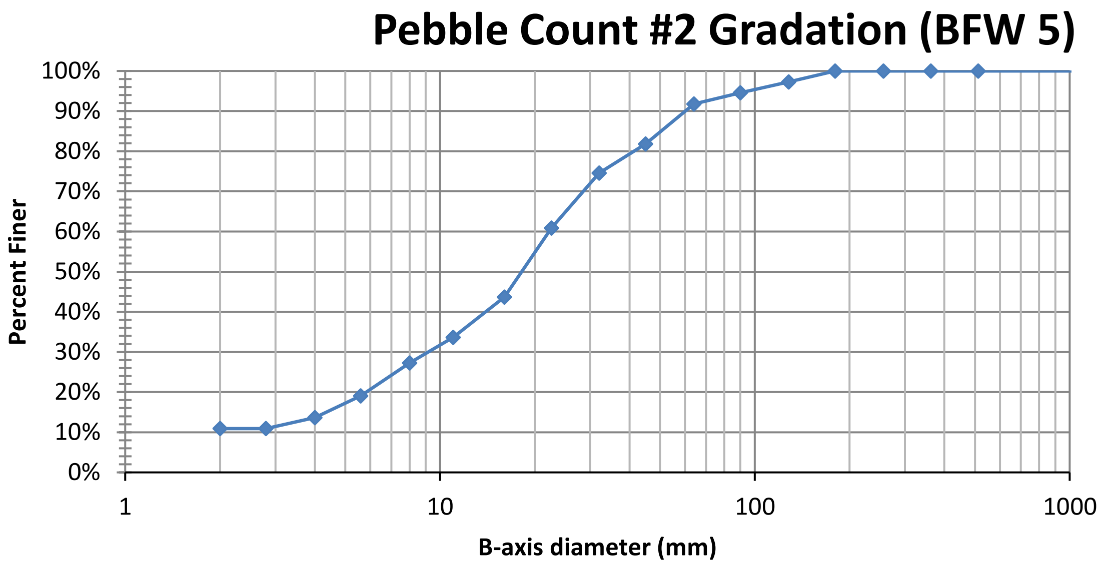


Figure 5. Pebble count #2 gradation at bankfull width measurement 5 in the upstream reach.

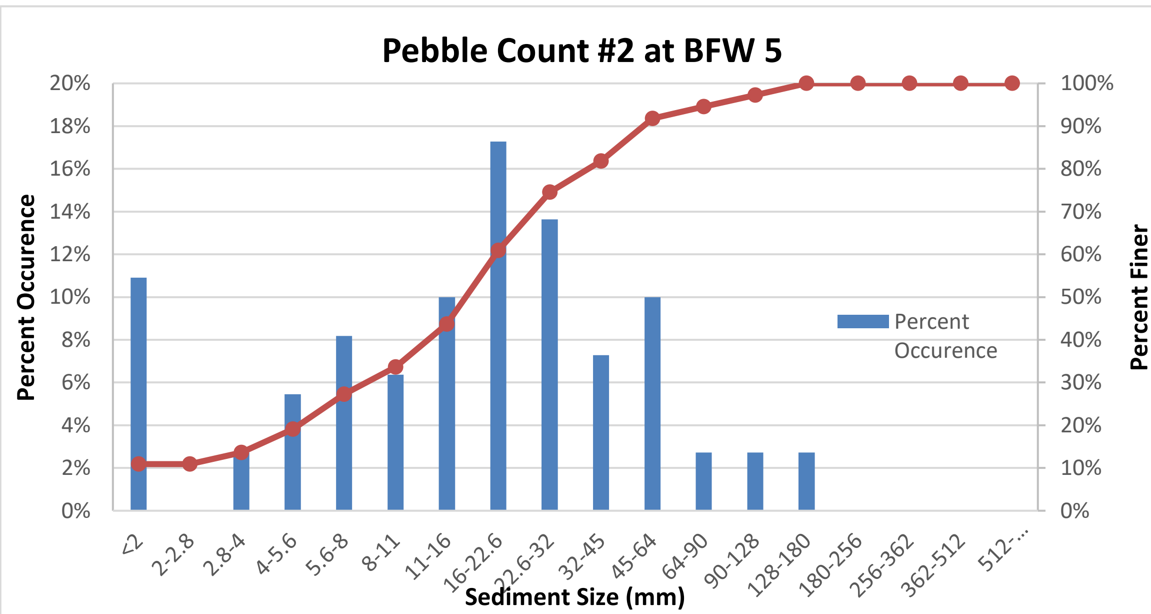


Figure 6. Percent occurrence by sediment size for the pebble count at bankfull width measurement 5 in the upstream reach

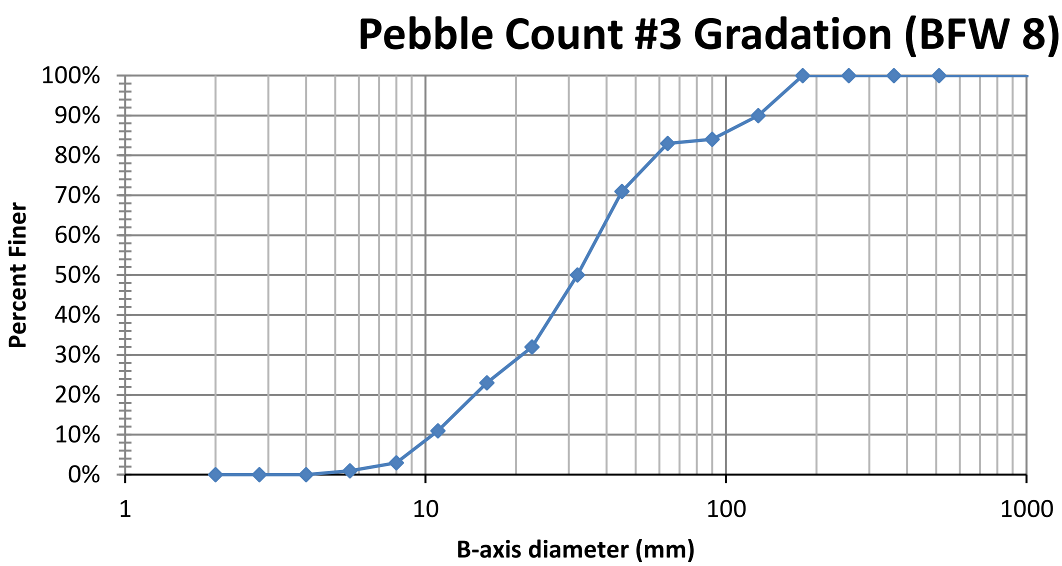


Figure 7. Pebble count #3 gradation at bankfull width measurement 8 in the upstream reach.

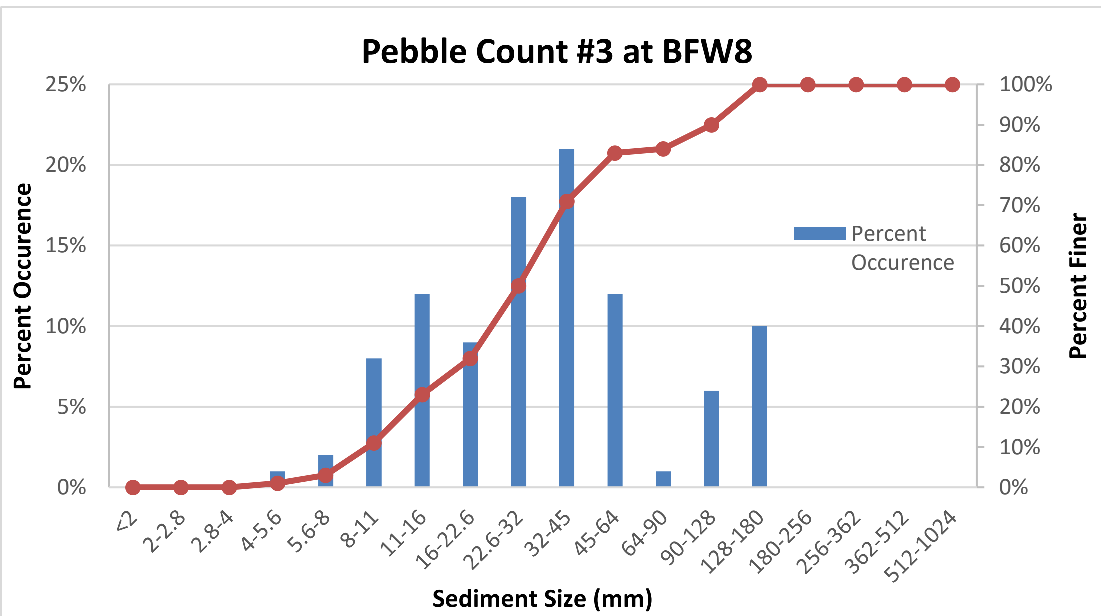


Figure 8. Percent occurrence by sediment size for the pebble count at bankfull width measurement 8 in the upstream reach.

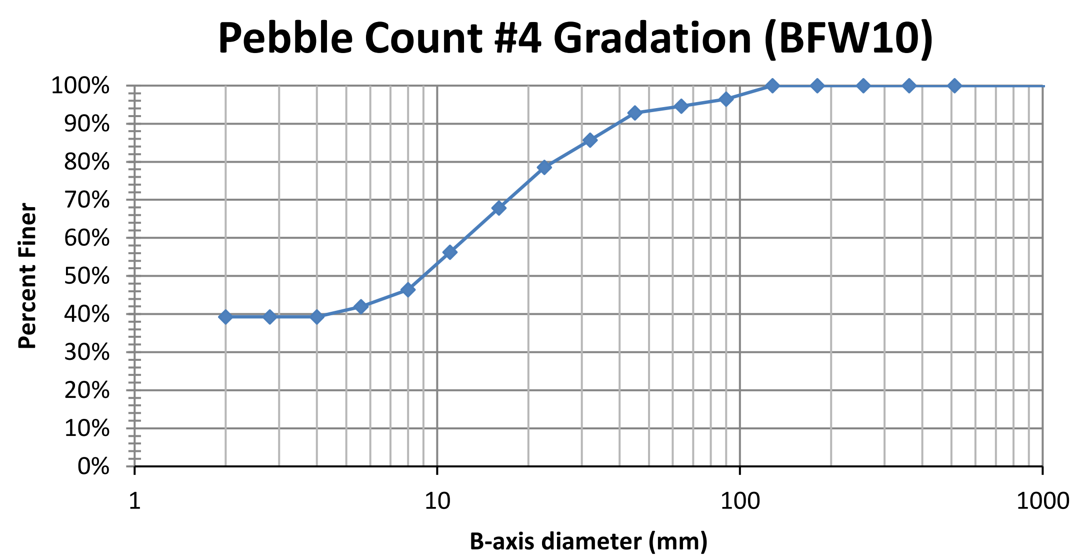


Figure 9. Pebble count #4 gradation at bankfull width measurement 10 in the downstream reach.

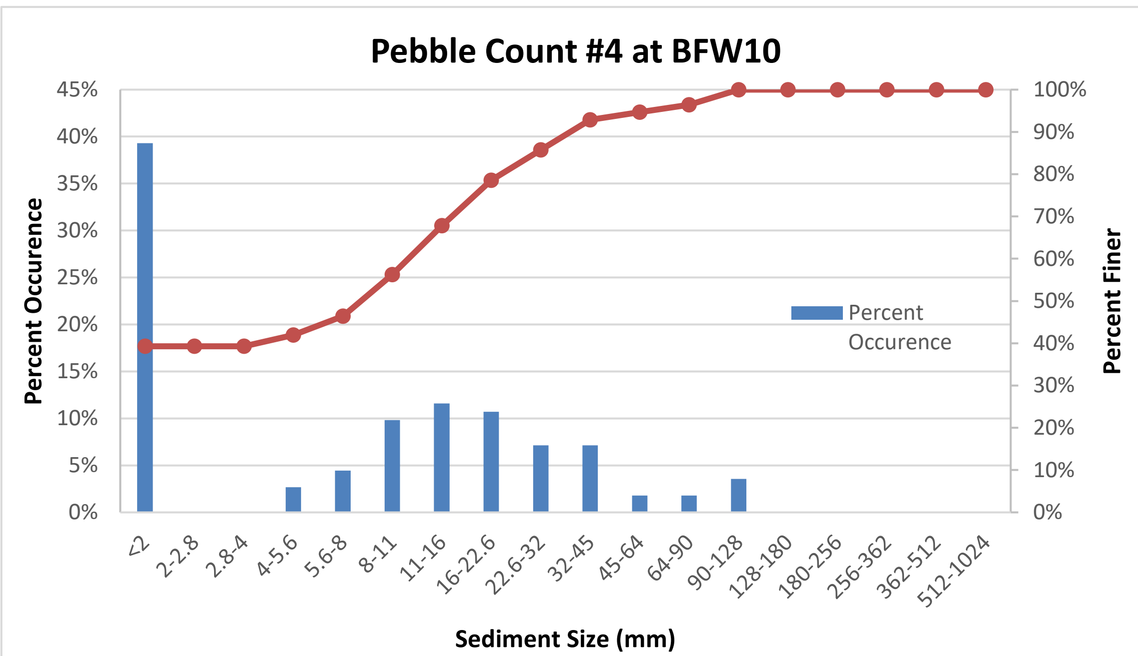


Figure 10. Percent occurrence by sediment size for the pebble count at bankfull width measurement 10 in the downstream reach

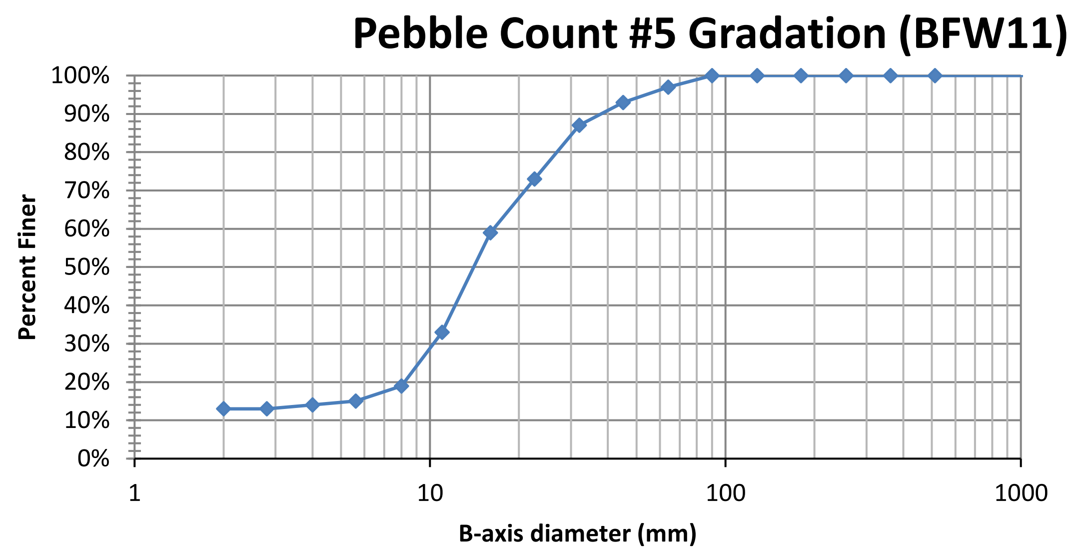


Figure 11. Pebble count #5 gradation at bankfull width measurement 11 in the downstream reach.

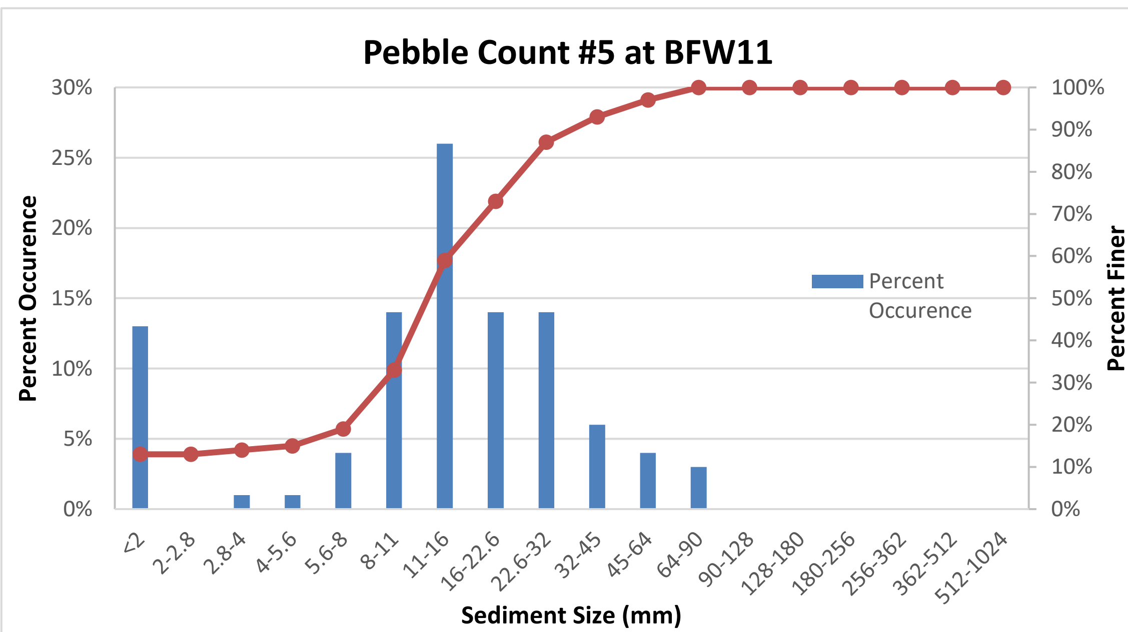


Figure 12. Percent occurrence by sediment size for the pebble count at bankfull width measurement 11 in the downstream reach

Bankfull Width Concurrence Meeting:

The on-site BFW concurrence meeting was held on April 28, 2021. This site visit was preceded by a teleconference meeting on April 26, 2021 to provide WSDOT, WDFW, Lummi Nation, Upper Skagit Indian Tribe and the Skagit River System Cooperative background South Tributary BFW information.

On-site, Otak personnel met with representatives from WSDOT, WDFW and Lummi Nation to field verify the bankfull width measurements collected by Otak on January 27, 2021. Representatives from these entities verified BFW #1 (9.6 feet) measured by Otak. WSDOT, WDFW and the Lummi Nation concurred that all BFW measurements collected by Otak (on January 27, 2021) are suitable and accurate for the South Tributary with an overall average BFW measurement of 7.8 ft (and a range of 5.7 to 9.6 ft).

April 28, 2021 South Tributary Site Visit Attendees:
WSDOT: Gabe Ng; Beth Toberer; Jared Bentley
Lummi Nation: Gregg Dunphy
WDFW: Matt Curtis, Kevin Lautz
Otak: Dave Stewart, Jamie Bails, Jennifer Goldsmith

Photos:

Upstream Reach

Photo 1: Upstream Reach, looking upstream from culvert 995235.

Photo 2: Looking downstream towards inlet to Culvert 995236, January 2021.

Photo 3: Inlet to Culvert 995236, January 2021.


Photo 4: Small boulders placed across stream within 30 feet upstream of culvert 995236.


Photo 5: Small boulders placed across stream within 30 feet upstream of culvert 995236.

Photo 6: Upstream reach, looking downstream towards culvert crossing under I-5 on ramp. Photo taken approximately at BFW 1, January 2021.

Photo 7: Upstream reach, looking upstream towards west. Photo taken approximately at BFW 1, January 2021.

Photo 8: Upstream Reach, Bankfull Width Measurement 1 (US BFW 1), January 2021.

Photo 9: Upstream Reach, US BFW 2, looking upstream. January 2021.

Photo 10: Upstream Reach, US BFW 3, looking downstream. January 2021.

Photo 11: Typical riffle with small boulders within upstream reach.

Photo 12: Upstream Reach, US BFW 4, looking upstream. January 2021.

Photo 13. Typical streambed gradation within gravel bar in upstream reach, near BFW 4.


Photo 14. Typical substrate sample within streambed, near BFW 4.


Photo 15. Typical stream conditions, looking downstream near BFW 4.

Photo 16. Typical step-pool formation, looking upstream near BFW 4.

Photo 17: Upstream Reach, US BFW 5, looking upstream. January 2021.


Photo 18: Upstream Reach, US BFW 6, looking upstream. January 2021.


Photo 19: Upstream Reach, US BFW 7, looking upstream. January 2021.


Photo 20: Upstream Reach, US BFW 8, looking upstream. January 2021.


Photo 21: Typical tree cover conditions within upstream reach.

Photo 22: Typical fallen trees across stream channel within upstream reach.

Project Reach

Photo 23. Outlet from culvert 995236 on right, and inlet to Culvert 995235 on left.

Photo 24. Inlet to culvert 995235.

Photo 25. Outlet from culvert 995235 and inlet to culvert 995234.


Photo 26. Outlet from culvert 995234 and inlet to culvert 995233.


Photo 27. Outlet from culvert 995233 and inlet to culvert 995232.

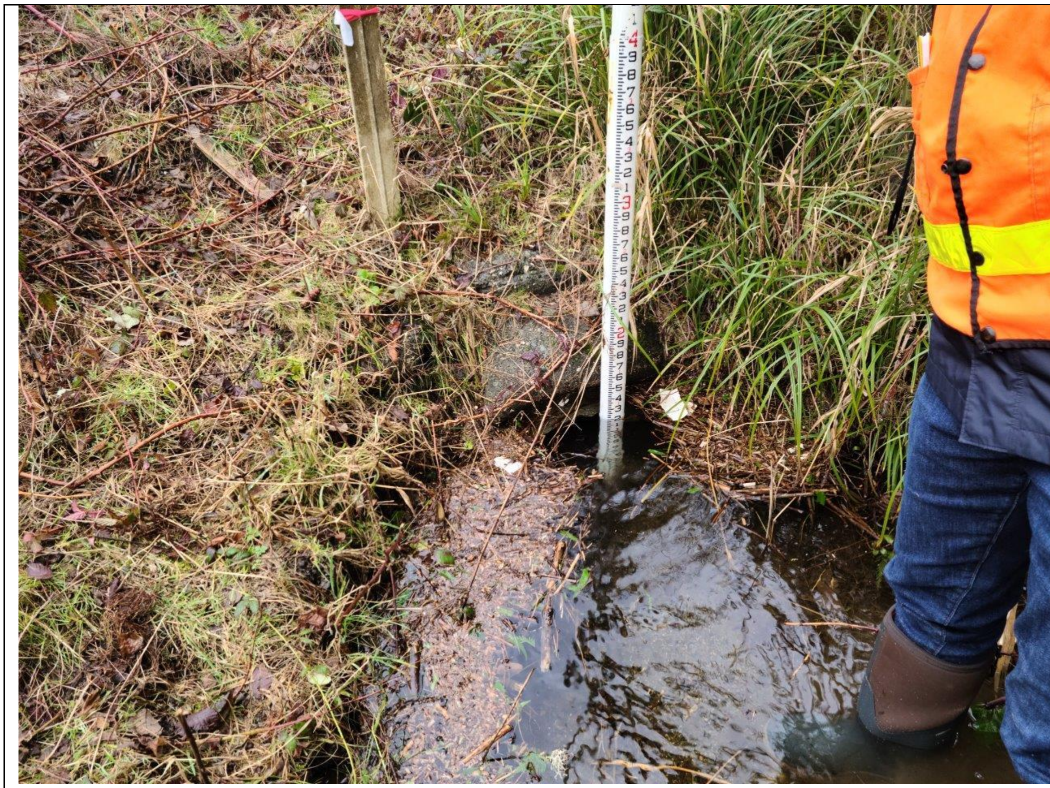


Photo 28: Outlet of culvert 995232, Sediment deposition at outlet has embedded culvert clearance to approximately 1' at outlet. January 2021.

Photo 29: Typical stream conditions downstream of culvert 995232, looking downstream.

Photo 30: Bankfull Width Measurement 9, within the project reach, looking downstream, approximately 50 feet upstream from culvert 995245. (Not considered representative due to modified, non-natural stream channel).

Photo 31: Typical substrate materials at location of BFW 9, including high clay content within channel bed and banks.

Photo 32: Stream channel conditions looking downstream towards culvert 995245 inlet.

Photo 33: Inlet to culvert 995245, under Lake Samish Road and the I-5 on-ramp/off-ramp intersection.

Downstream Reach

Photo 34. Site 995245 culvert outlet.

Photo 35. Downstream reach of Site 995245 culvert, Bankfull Width 9 (not considered representative due to channel modifications).

Photo 36. Typical streambed substrate within downstream reach, high amount of sand embedding gravels.

Photo 37. Typical stream conditions within downstream reach, looking downstream from Bankfull Width measurement 9.

Photo 38. Downstream reach of Site 995245 culvert, Bankfull Width 10 (not considered representative due to channel modifications).

Photo 39. Typical streambed gravel within riffles formed by small wood debris jam in downstream reach, looking upstream.

Photo 40. Typical downstream reach and access road, looking downstream.

Photo 41. Typical downstream reach and access road, looking upstream.


Photo 42. Typical stream conditions downstream of the culvert crossing under Barleen road, with an installed log weir downstream.


Photo 43. Location of Bankfull Width measurement 12, downstream of the culvert under Barleen road and the log weir.

Appendix C: SRH-2D Model Results

Existing Conditions (24 graphics total)

2-Year Flow; 25-Year Flow; 50-Year Flow; 100-Year Flow; 500-Year Flow; 2080 100 Year Flow

- Flow Depth (ft)
- Water Surface Elevation (ft)
- Velocity (ft/sec)
- Shear Stress (psf)

Natural Conditions (24 graphics total)

2-Year Flow; 25-Year Flow; 50-Year Flow; 100-Year Flow; 500-Year Flow; 2080 100 Year Flow

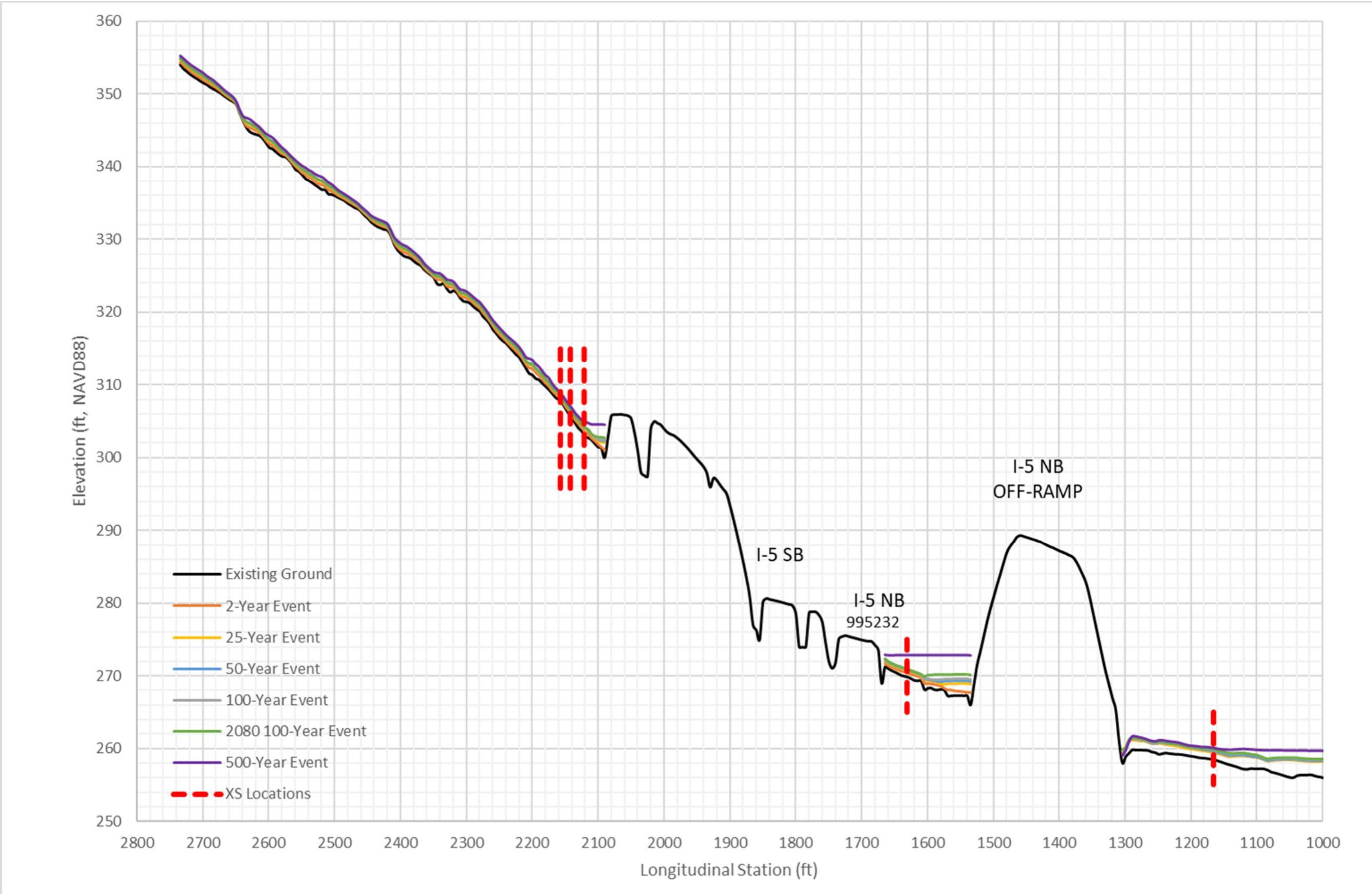
- Flow Depth (ft)
- Water Surface Elevation (ft)
- Velocity (ft/sec)
- Shear Stress (psf)

Proposed Conditions (24 graphics total)

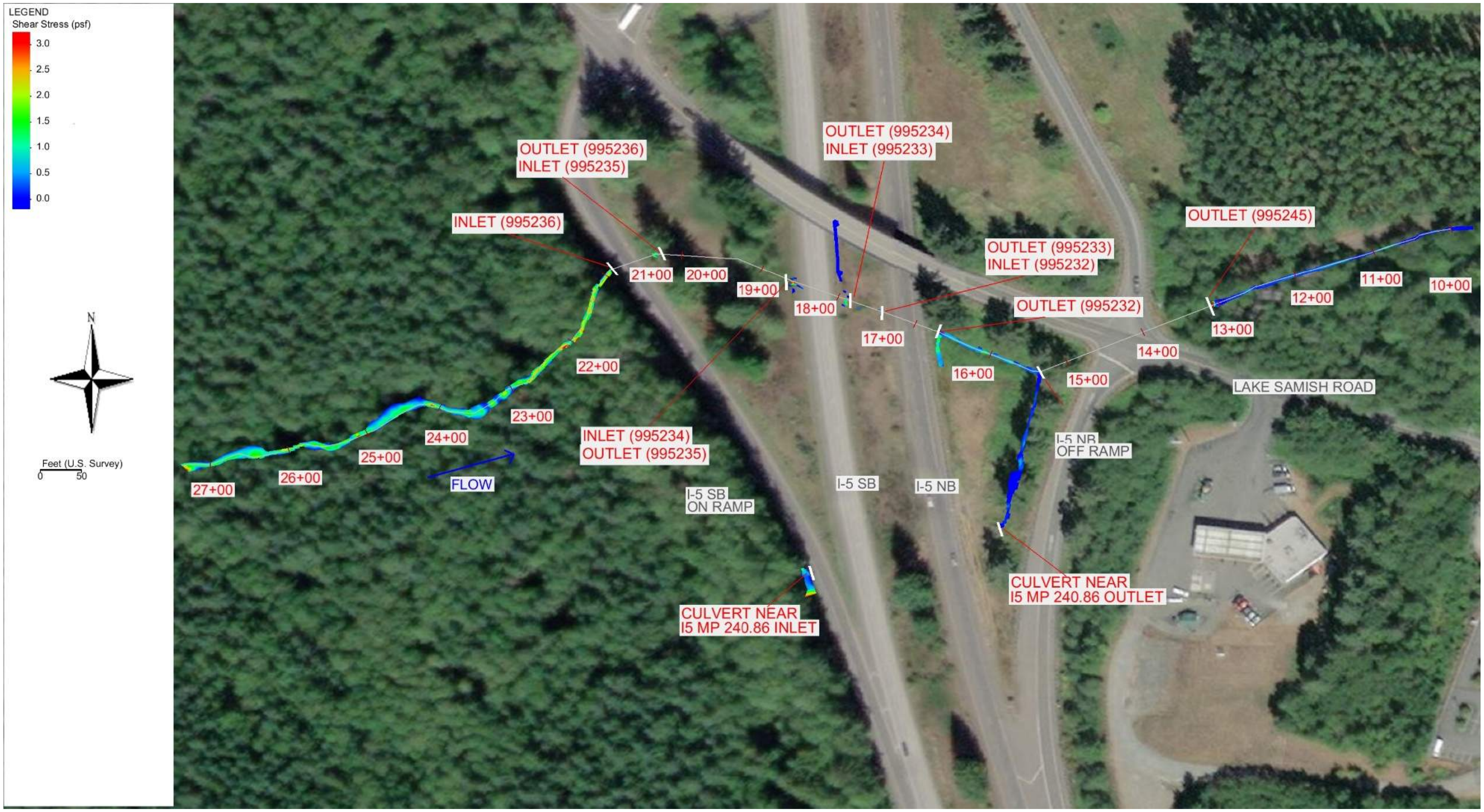
2-Year Flow; 25-Year Flow; 50-Year Flow; 100-Year Flow; 500-Year Flow; 2080 100 Year Flow

- Flow Depth (ft)
- Water Surface Elevation (ft)
- Velocity (ft/sec)
- Shear Stress (psf)

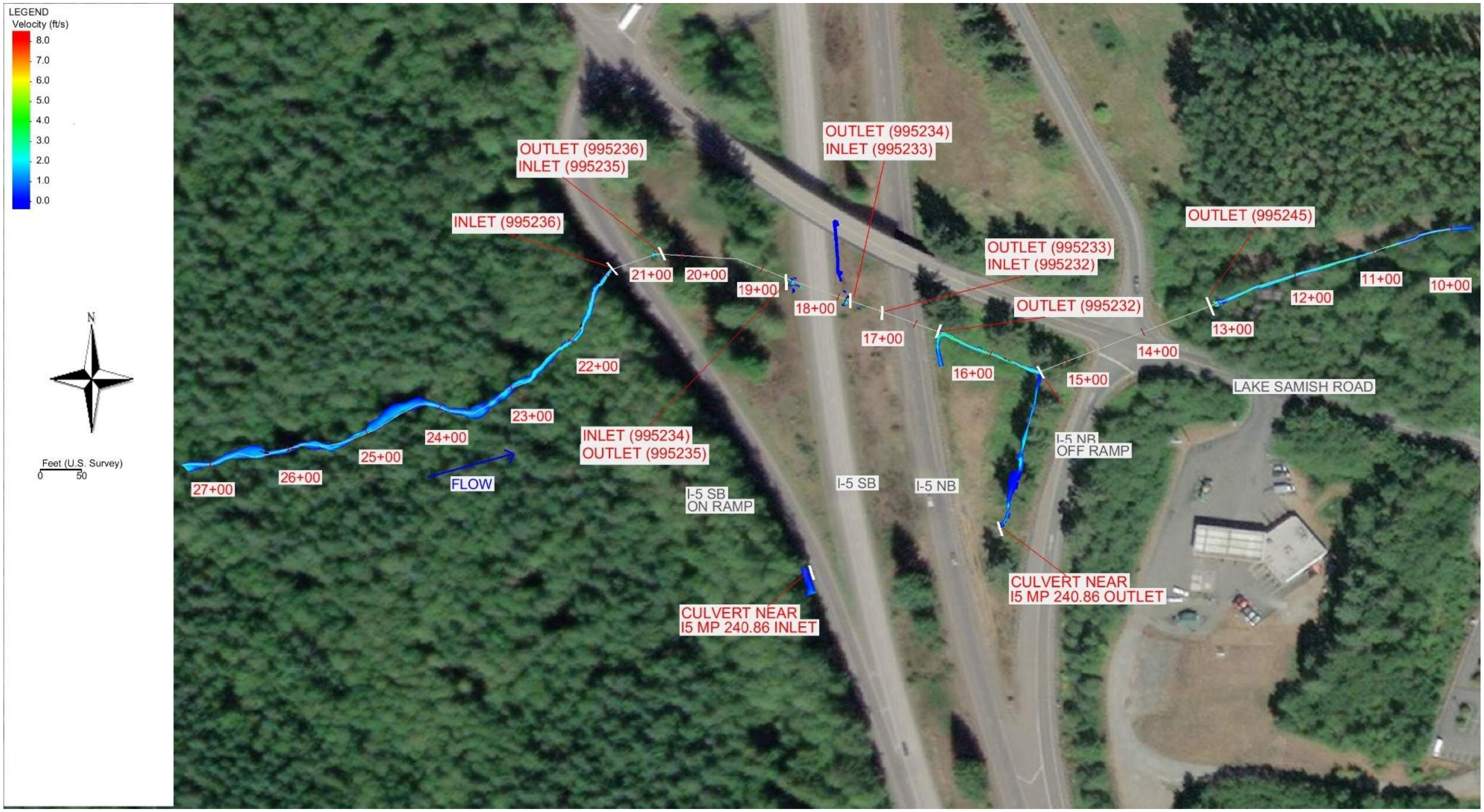
Existing Conditions Water Surface Profiles



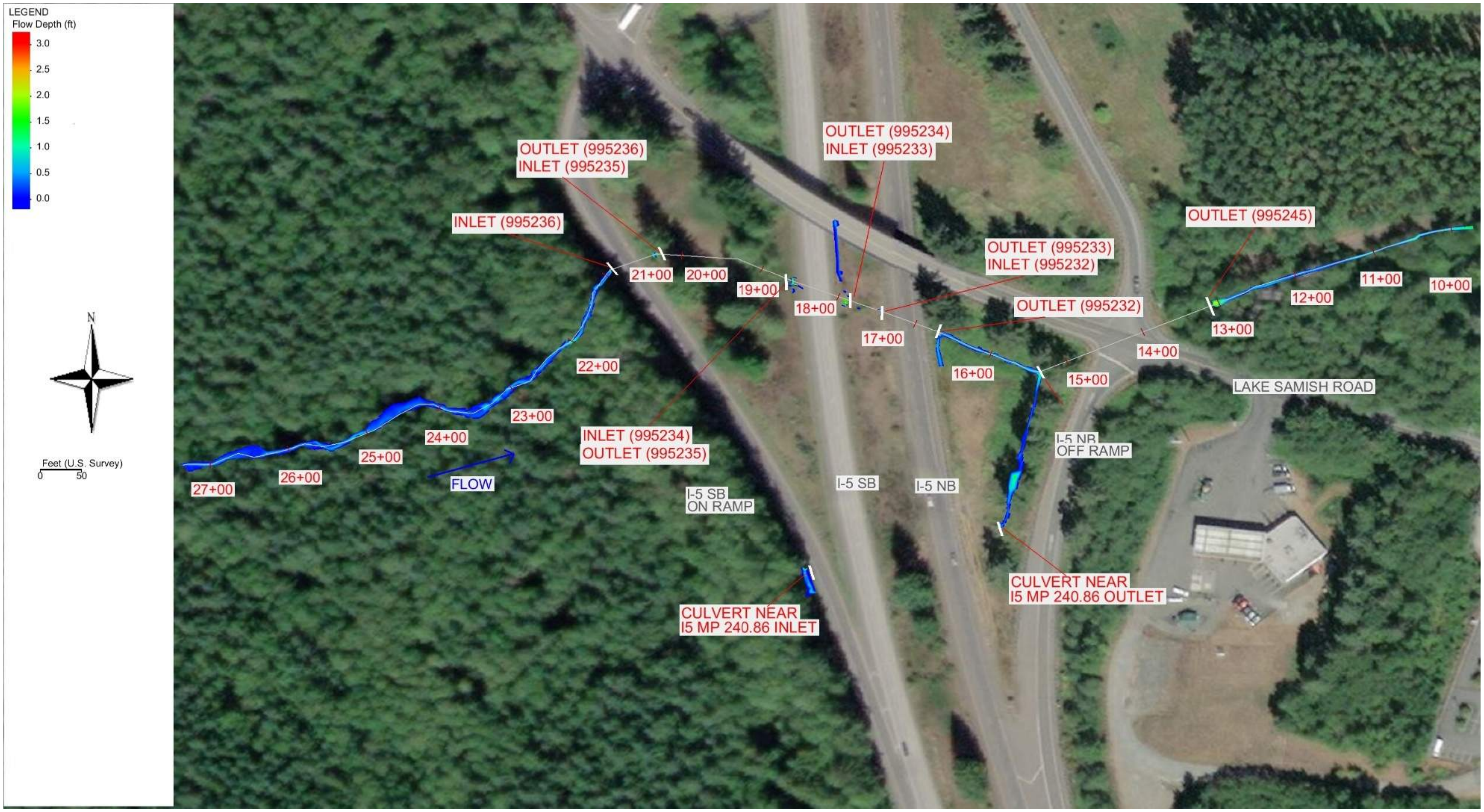
Existing Conditions, 2-Year Flow, Shear Stress (psf)



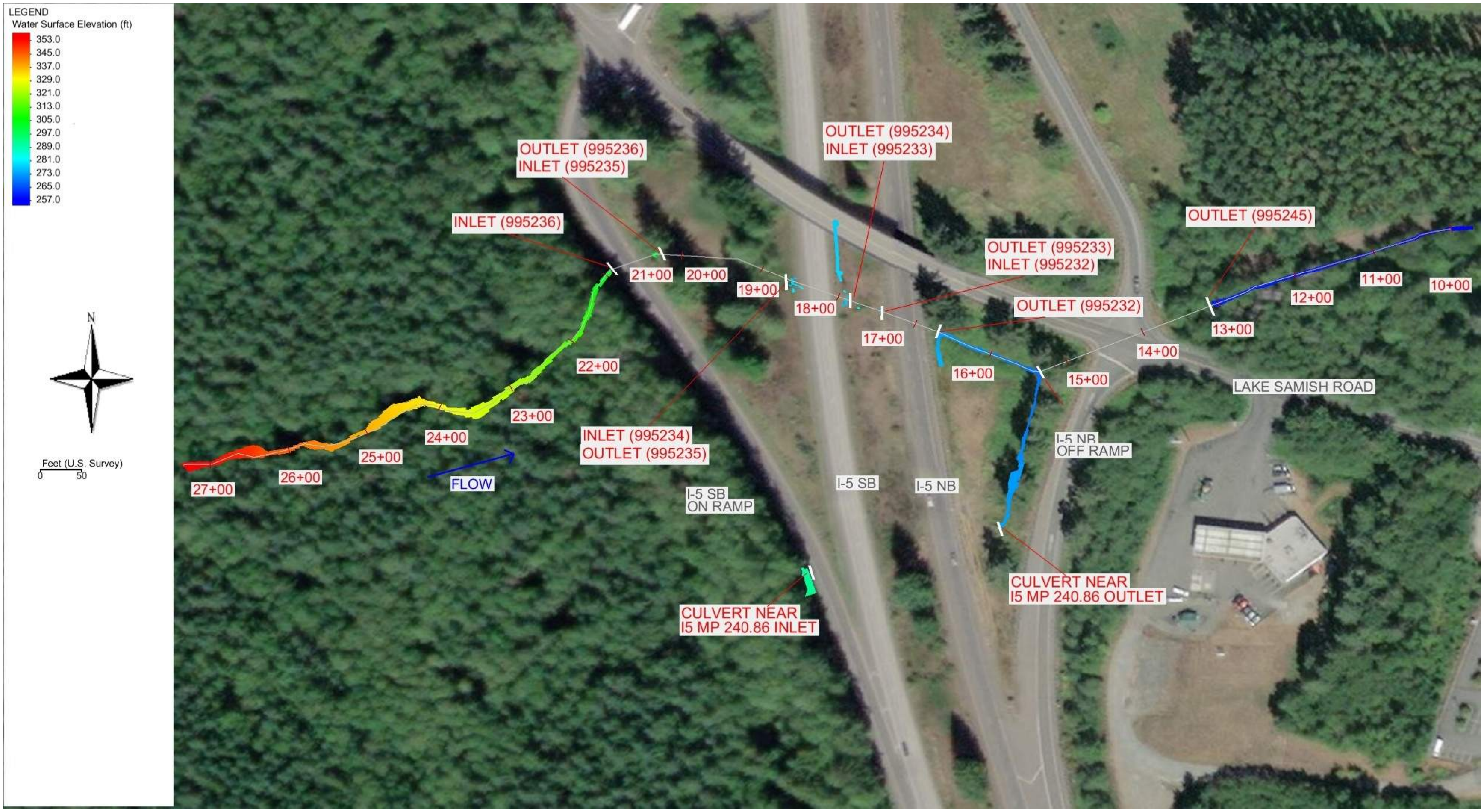
Existing Conditions, 2-Year Flow, Velocity (ft/s)



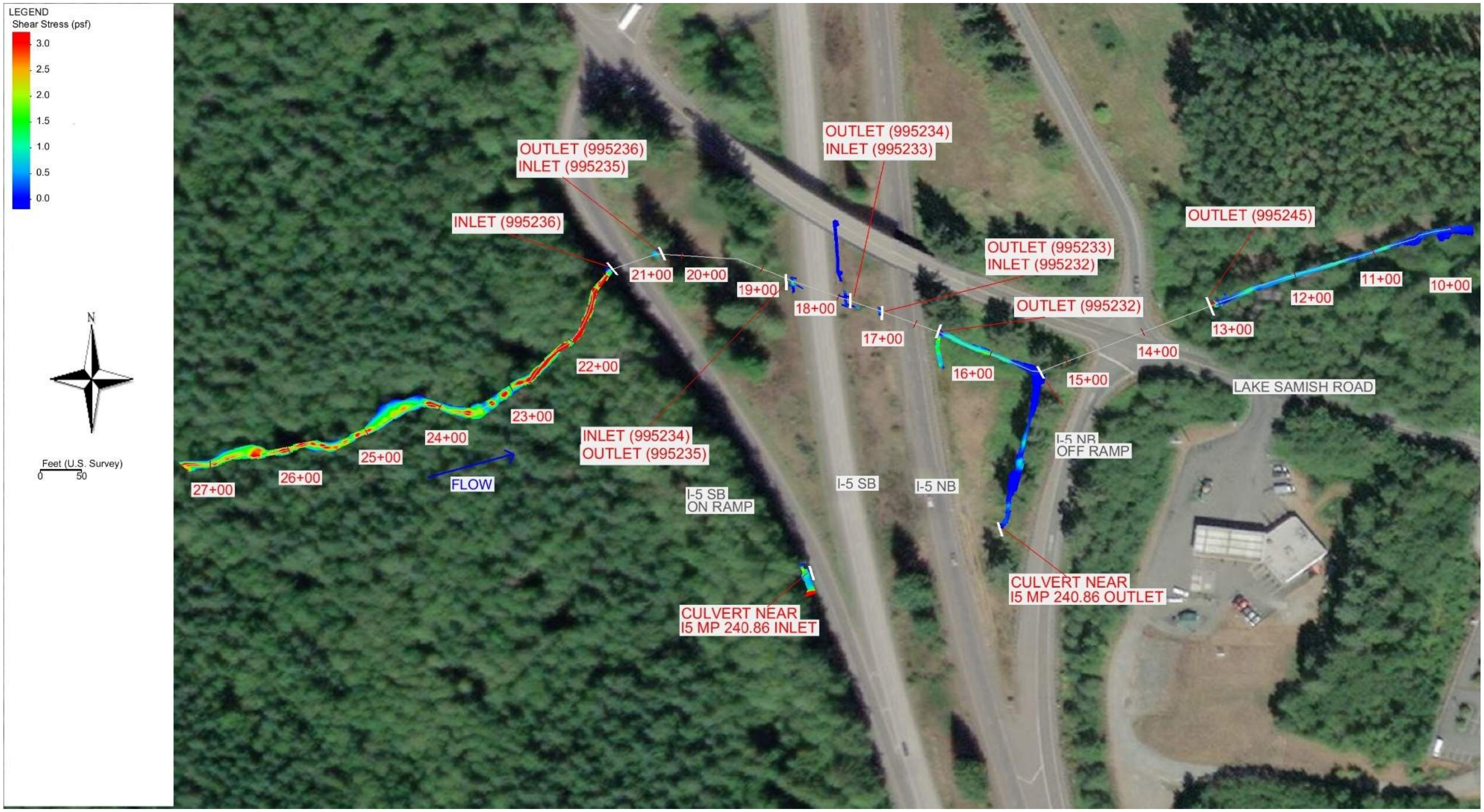
Existing Conditions, 2-Year Flow, Flow Depth (ft)



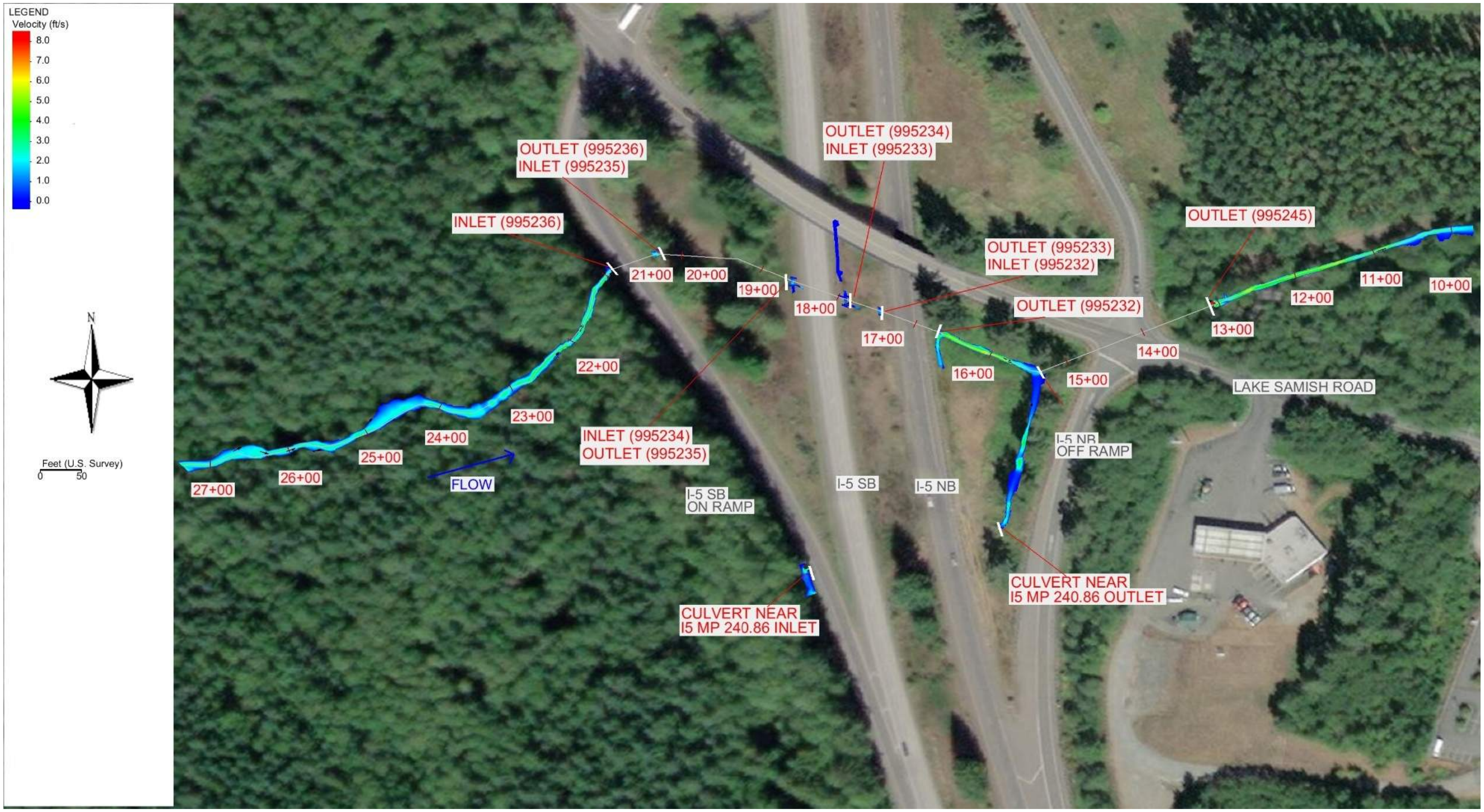
Existing Conditions, 2-Year Flow, Water Surface Elevation (ft)



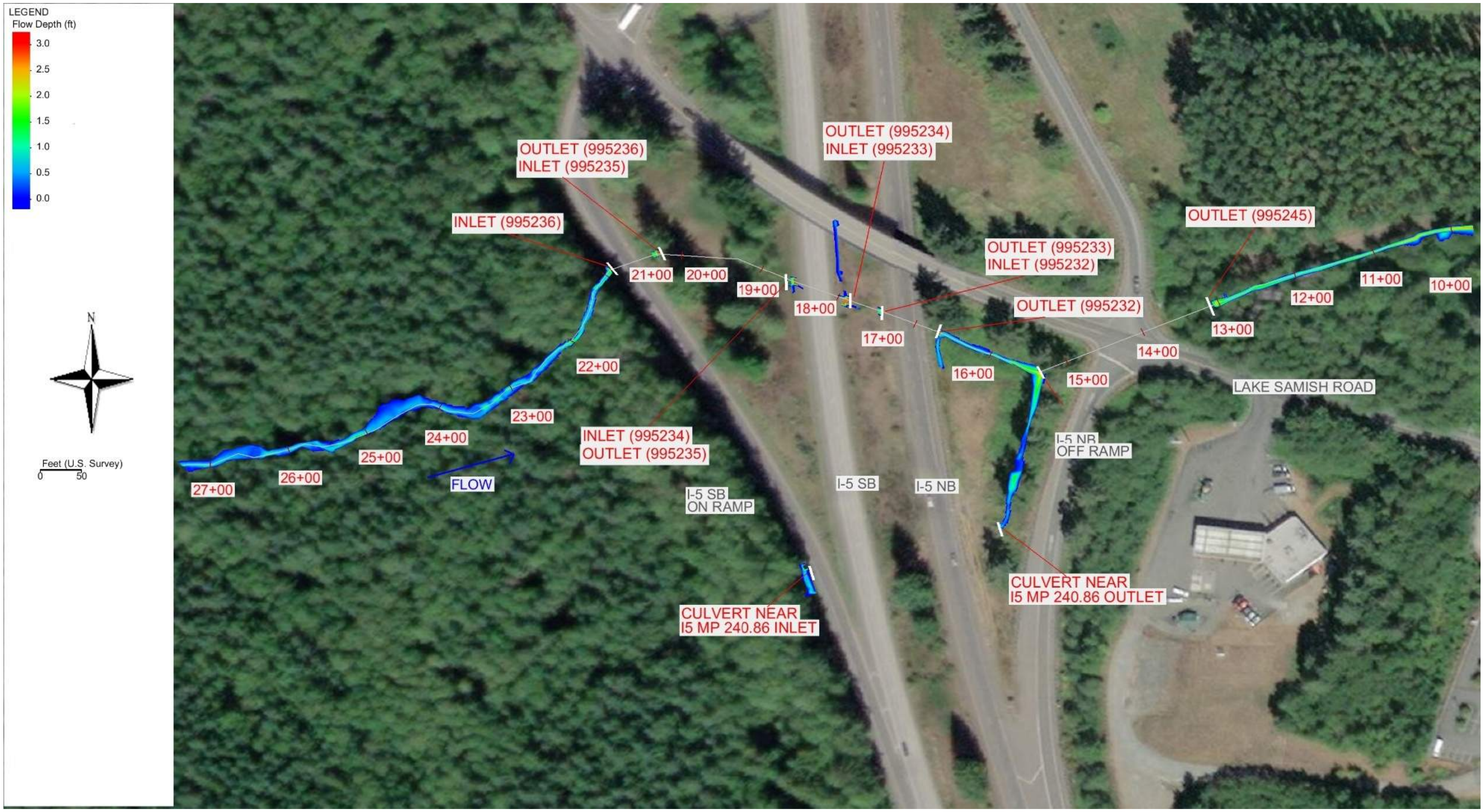
Existing Conditions, 25-Year Flow, Shear Stress (psf)



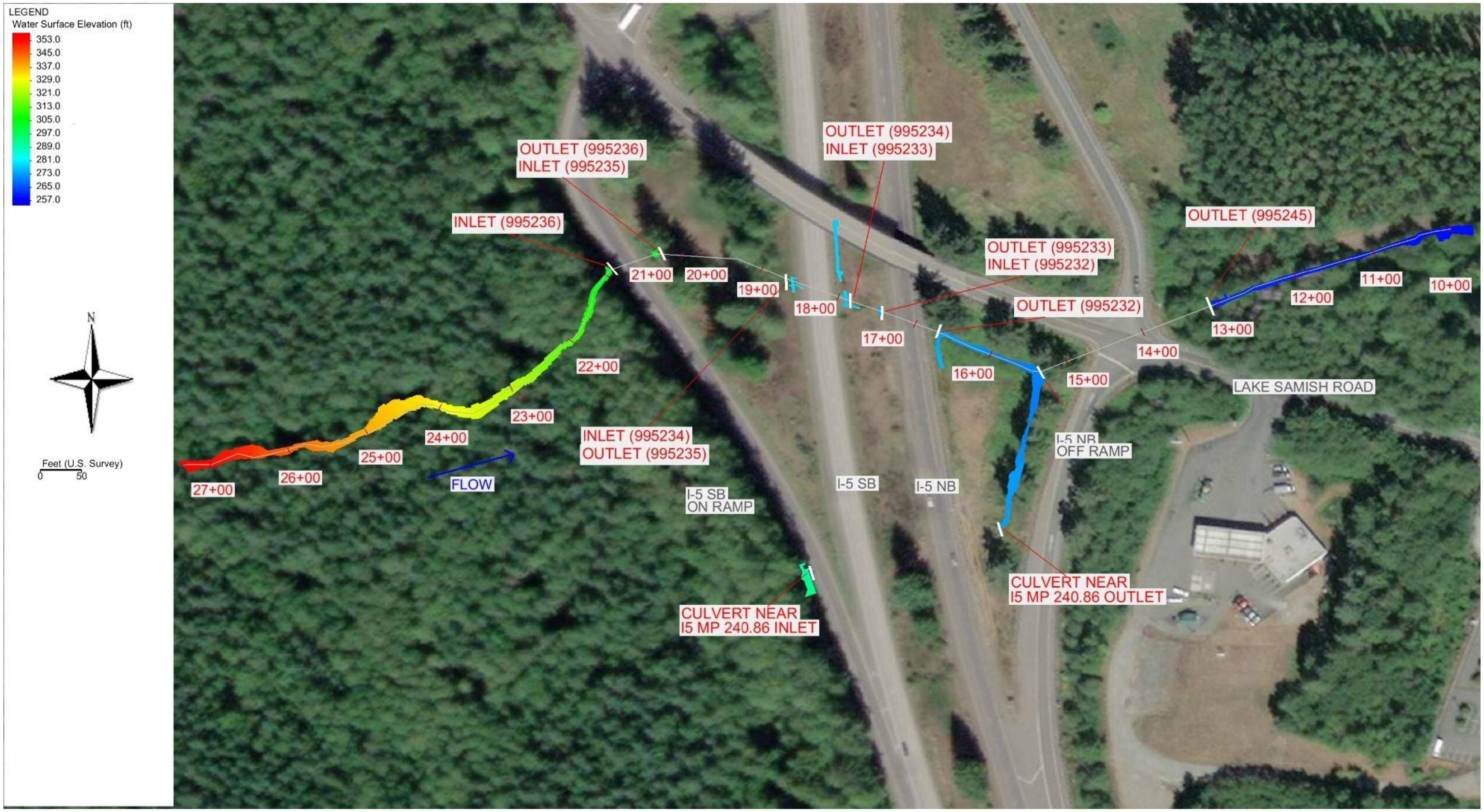
Existing Conditions, 25-Year Flow, Velocity (ft/s)



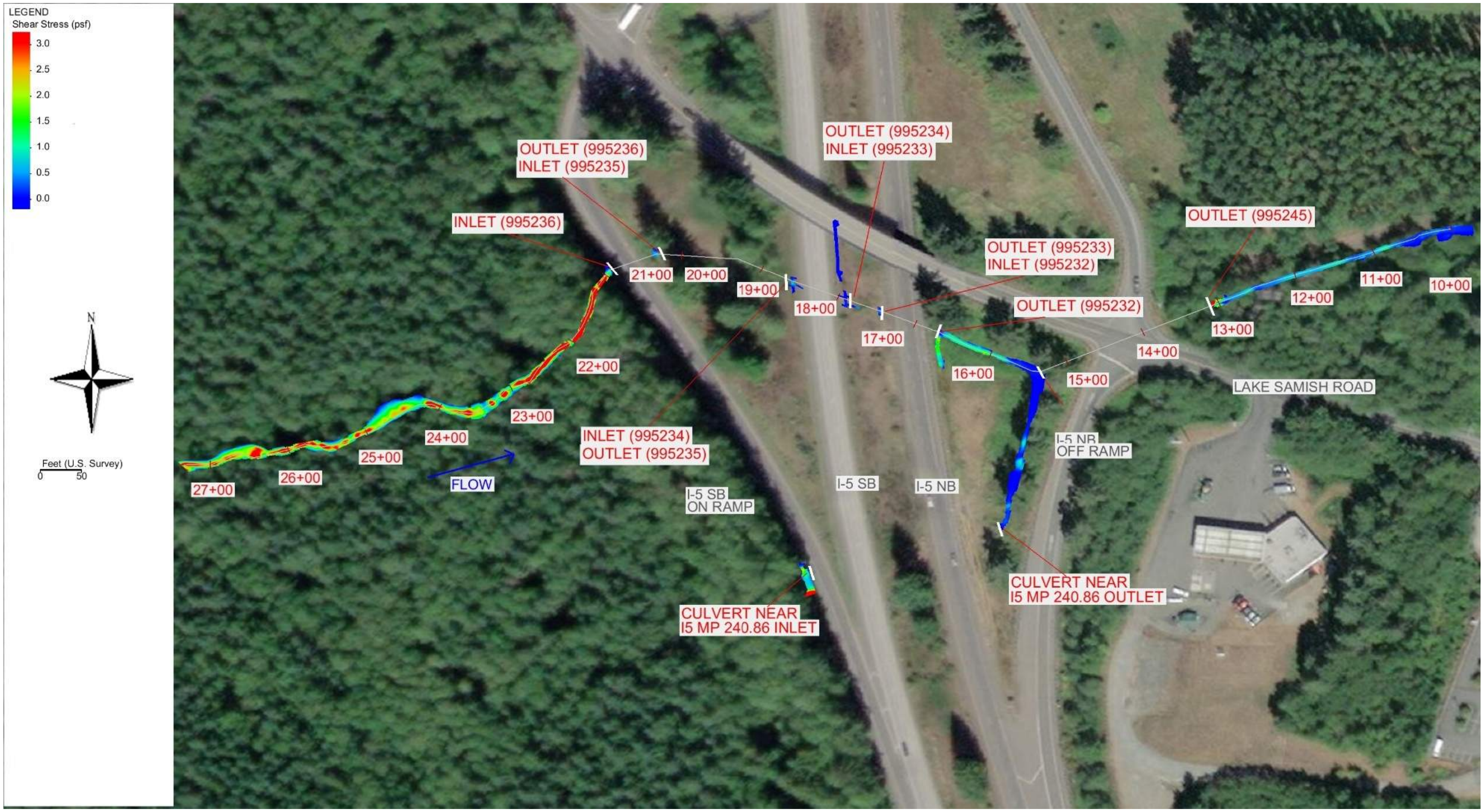
Existing Conditions, 25-Year Flow, Flow Depth (ft)



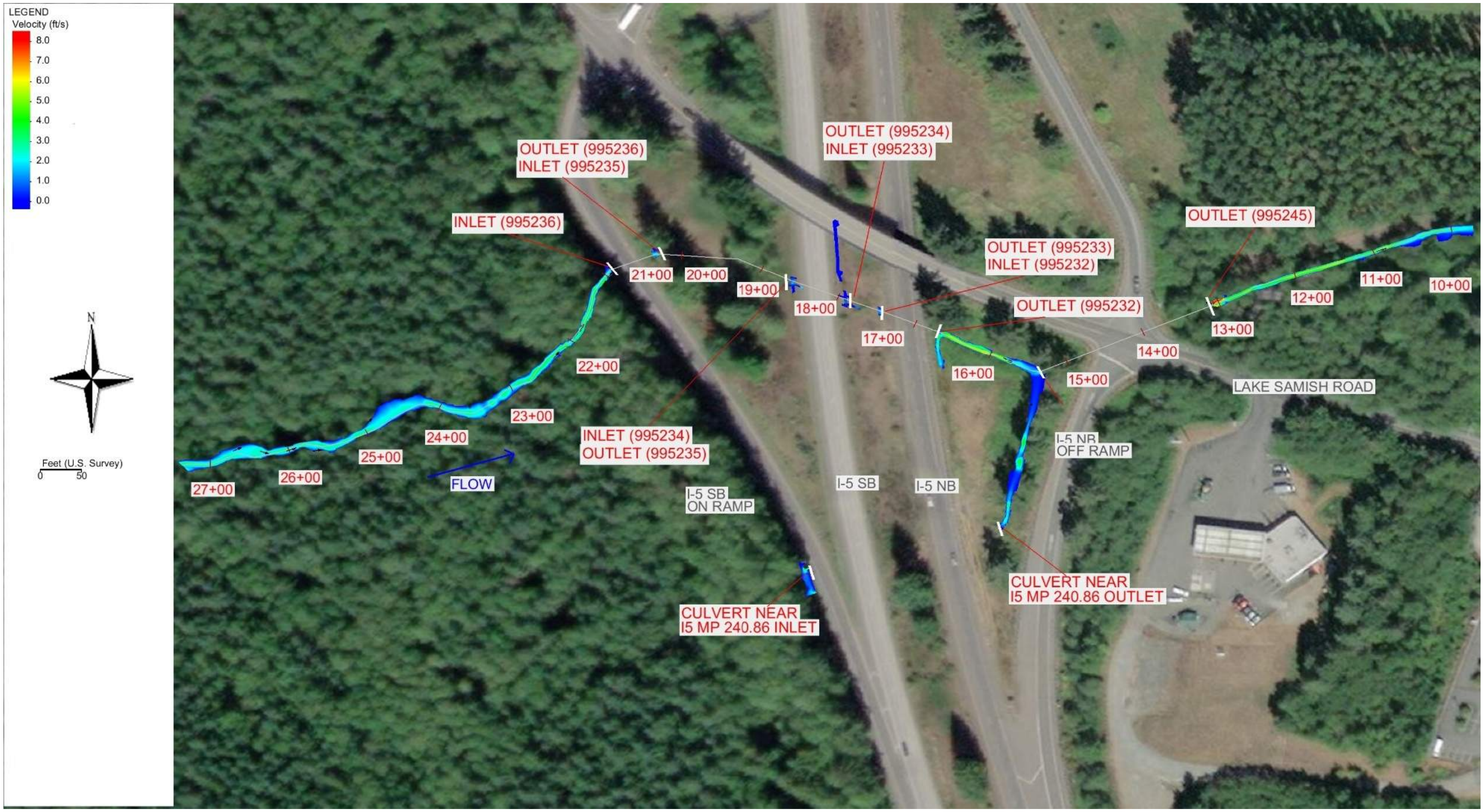
Existing Conditions, 25-Year Flow, Water Surface Elevation (ft)



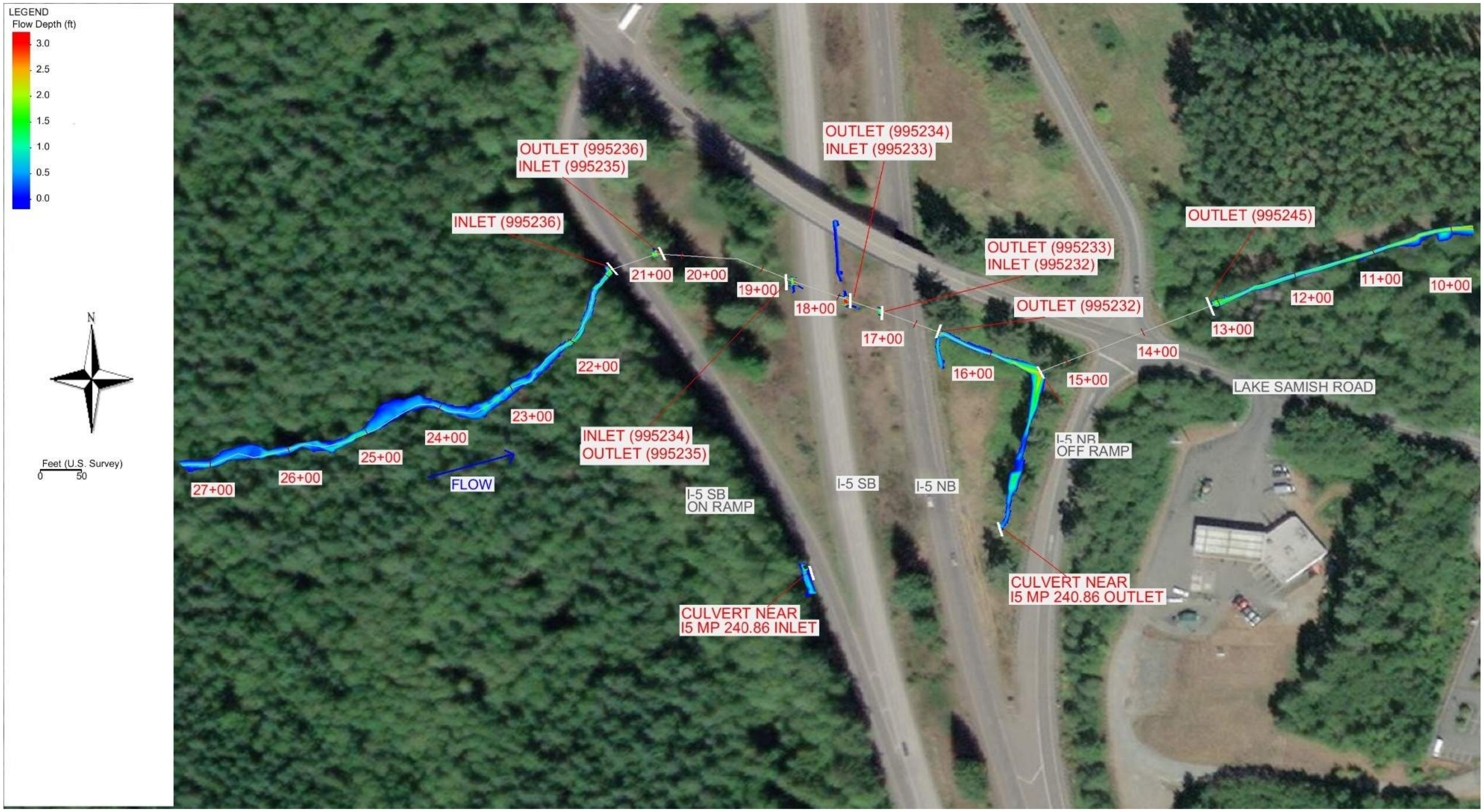
Existing Conditions, 50-Year Flow, Shear Stress (psf)



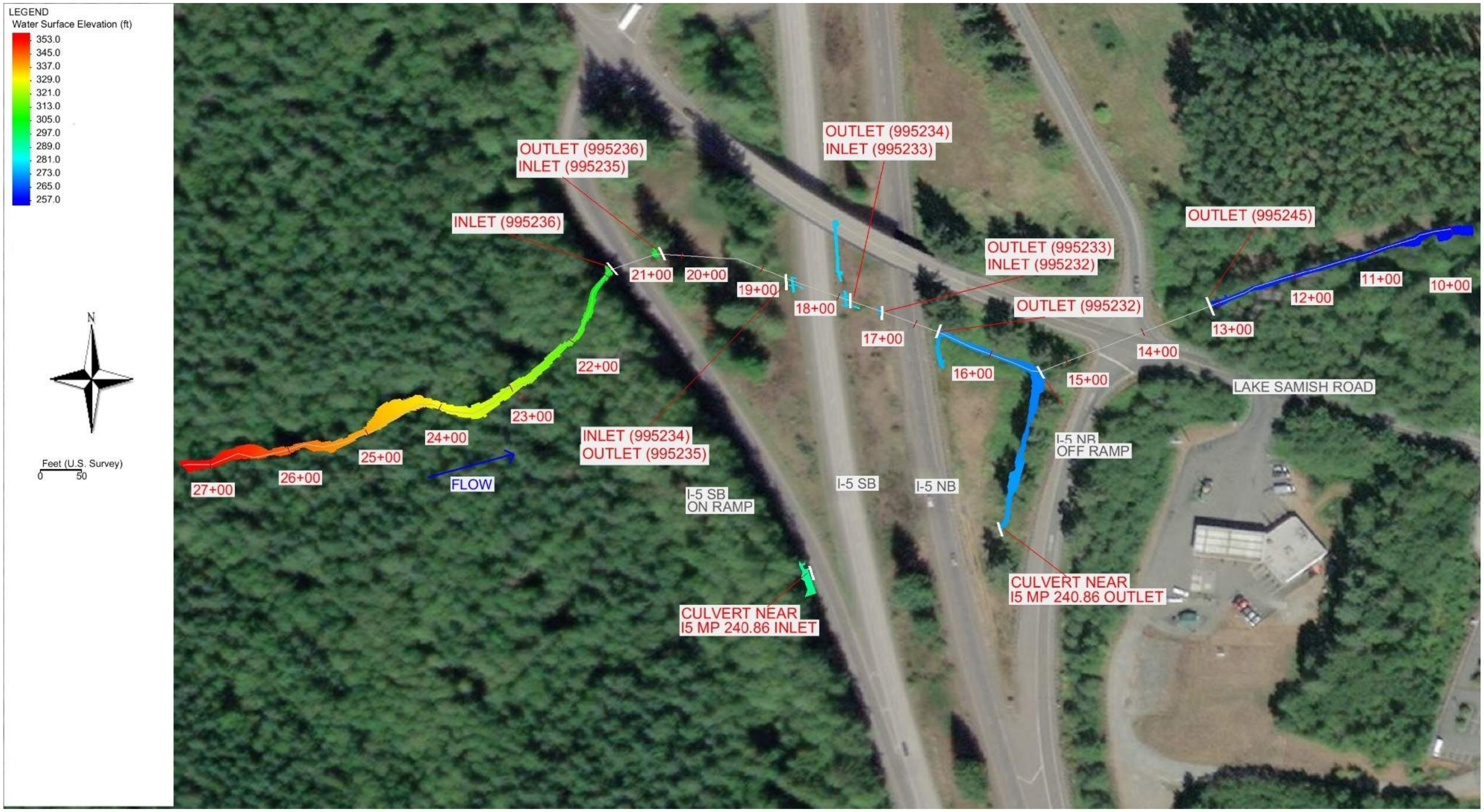
Existing Conditions, 50-Year Flow, Velocity (ft/s)



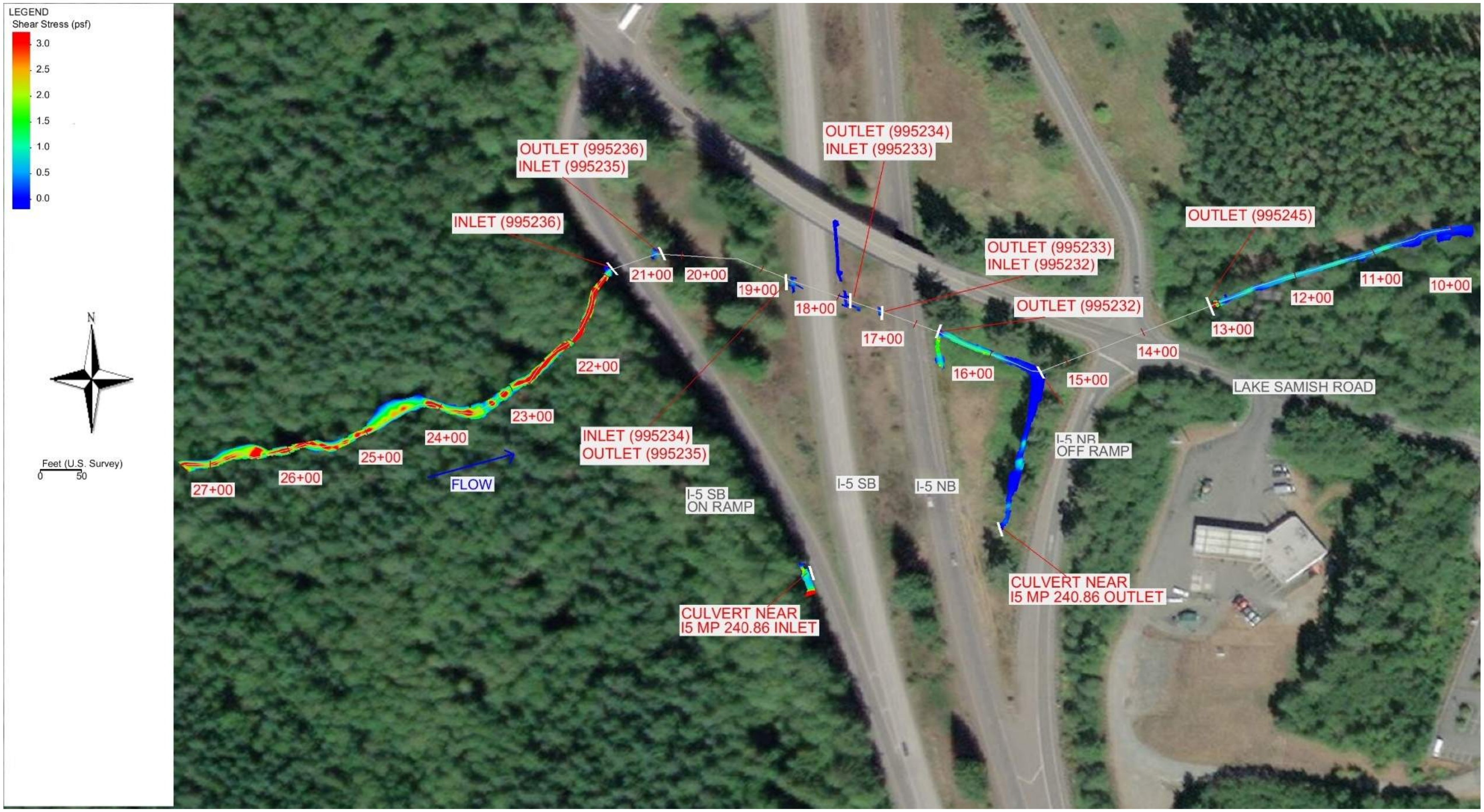
Existing Conditions, 50-Year Flow, Flow Depth (ft)



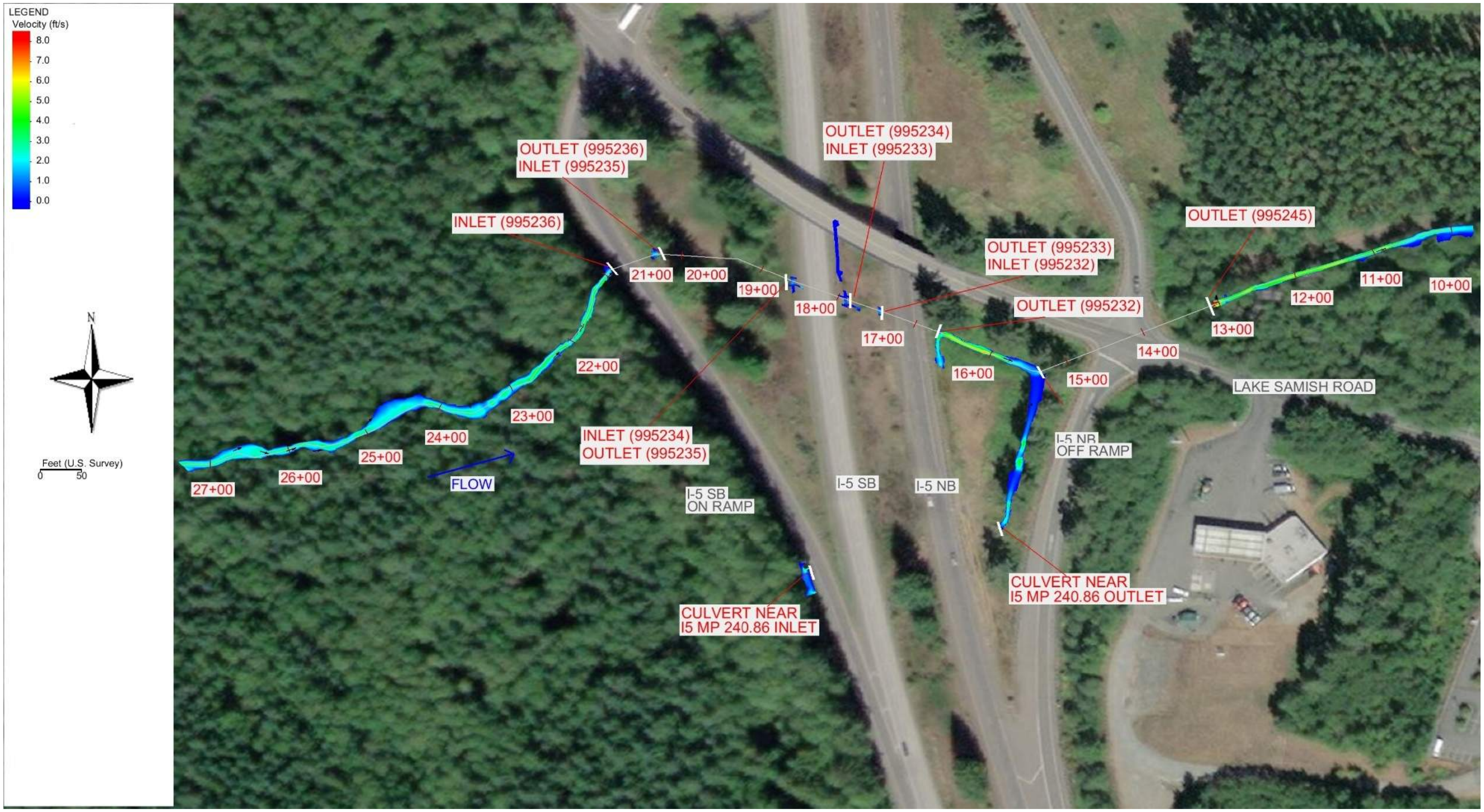
Existing Conditions, 50-Year Flow, Water Surface Elevation (ft)



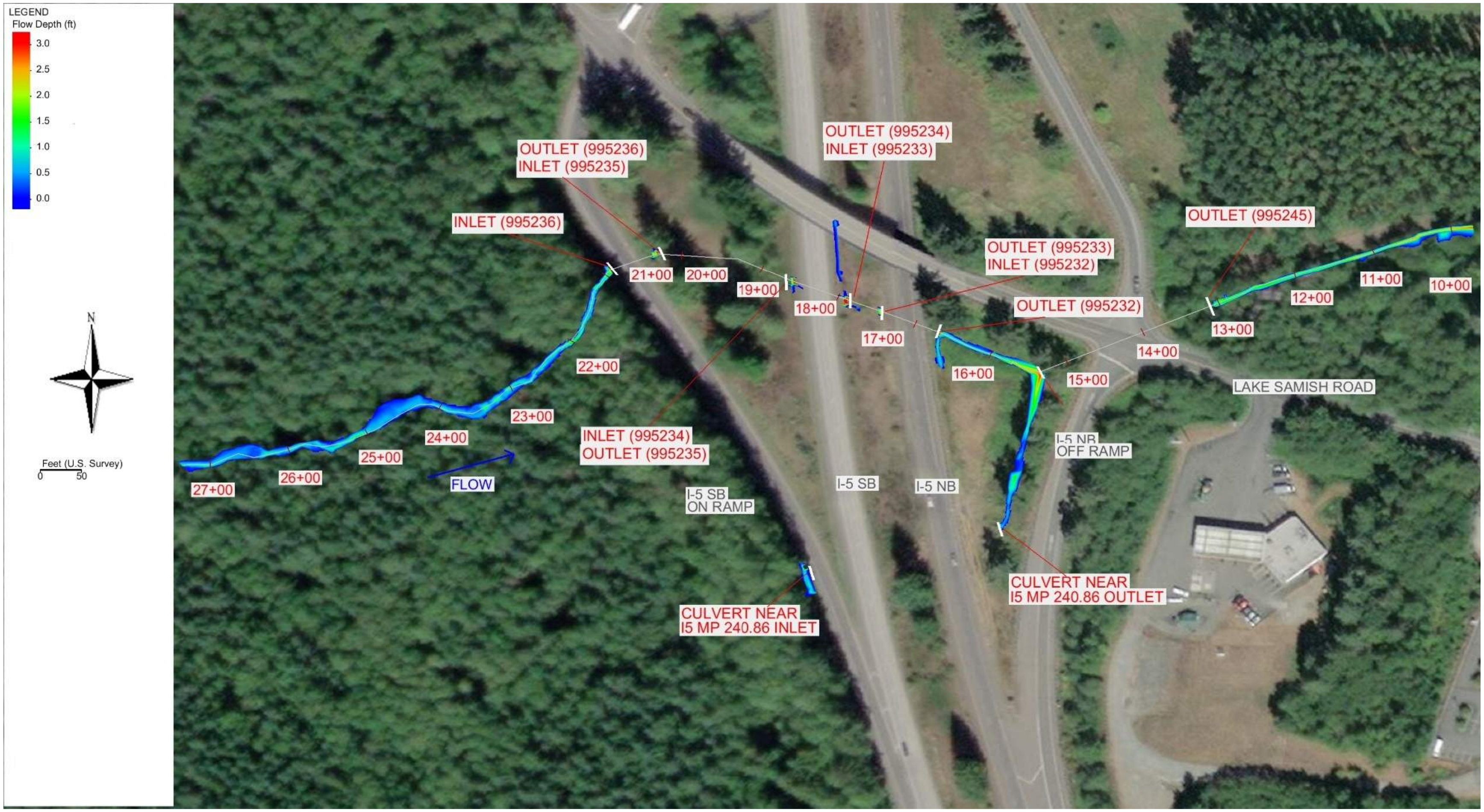
Existing Conditions, 100-Year Flow, Shear Stress (psf)



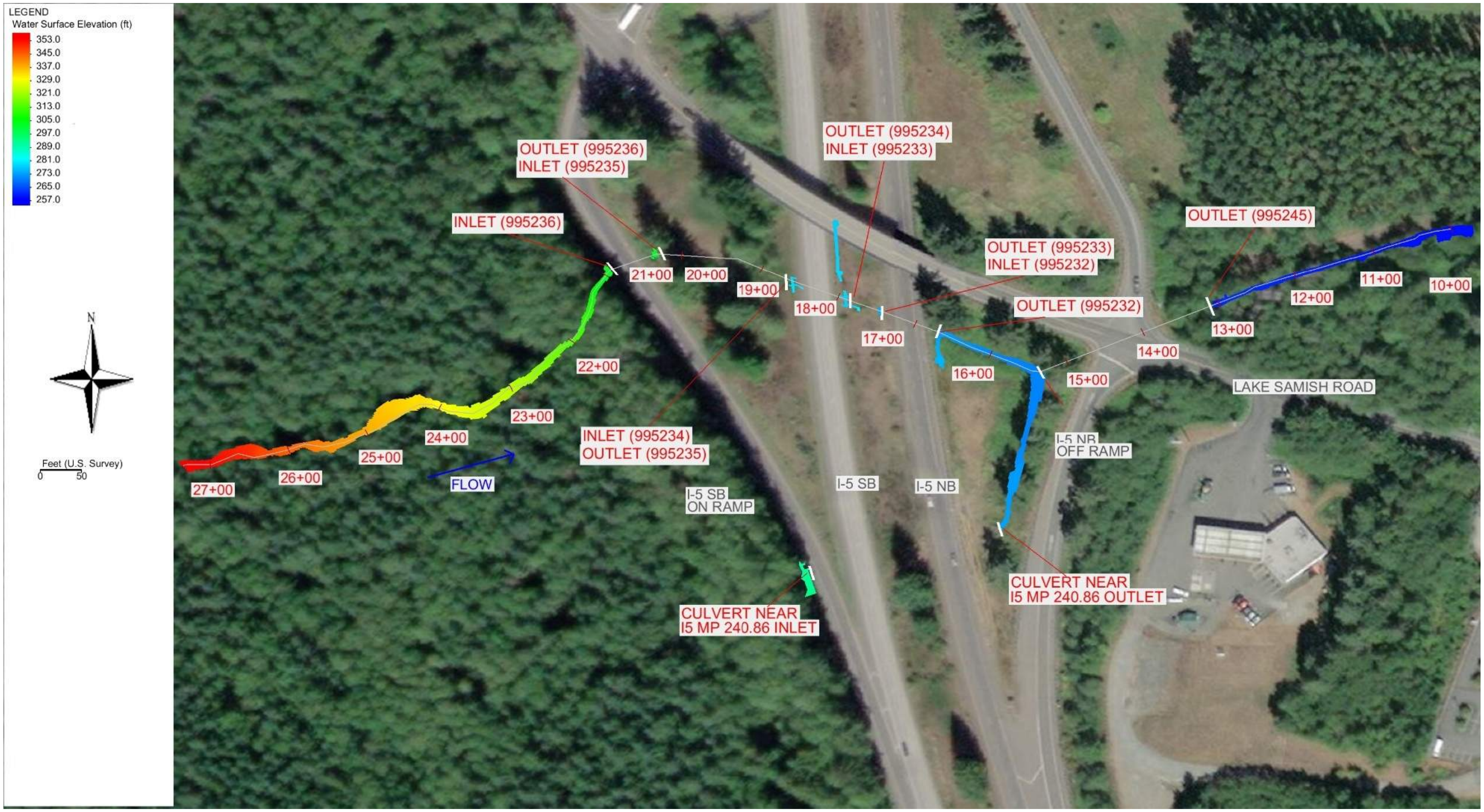
Existing Conditions, 100-Year Flow, Velocity (ft/s)



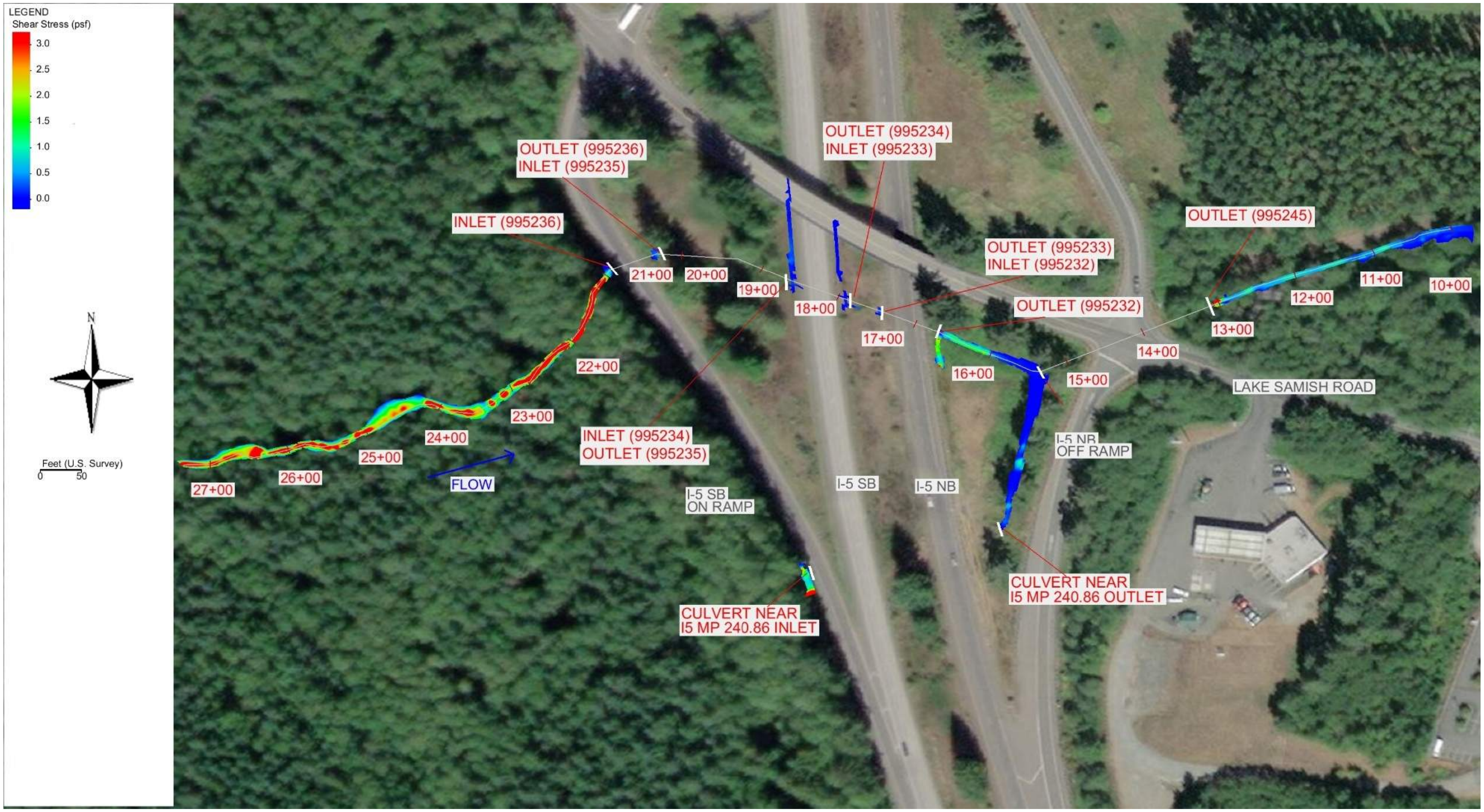
Existing Conditions, 100-Year Flow, Flow Depth (ft)



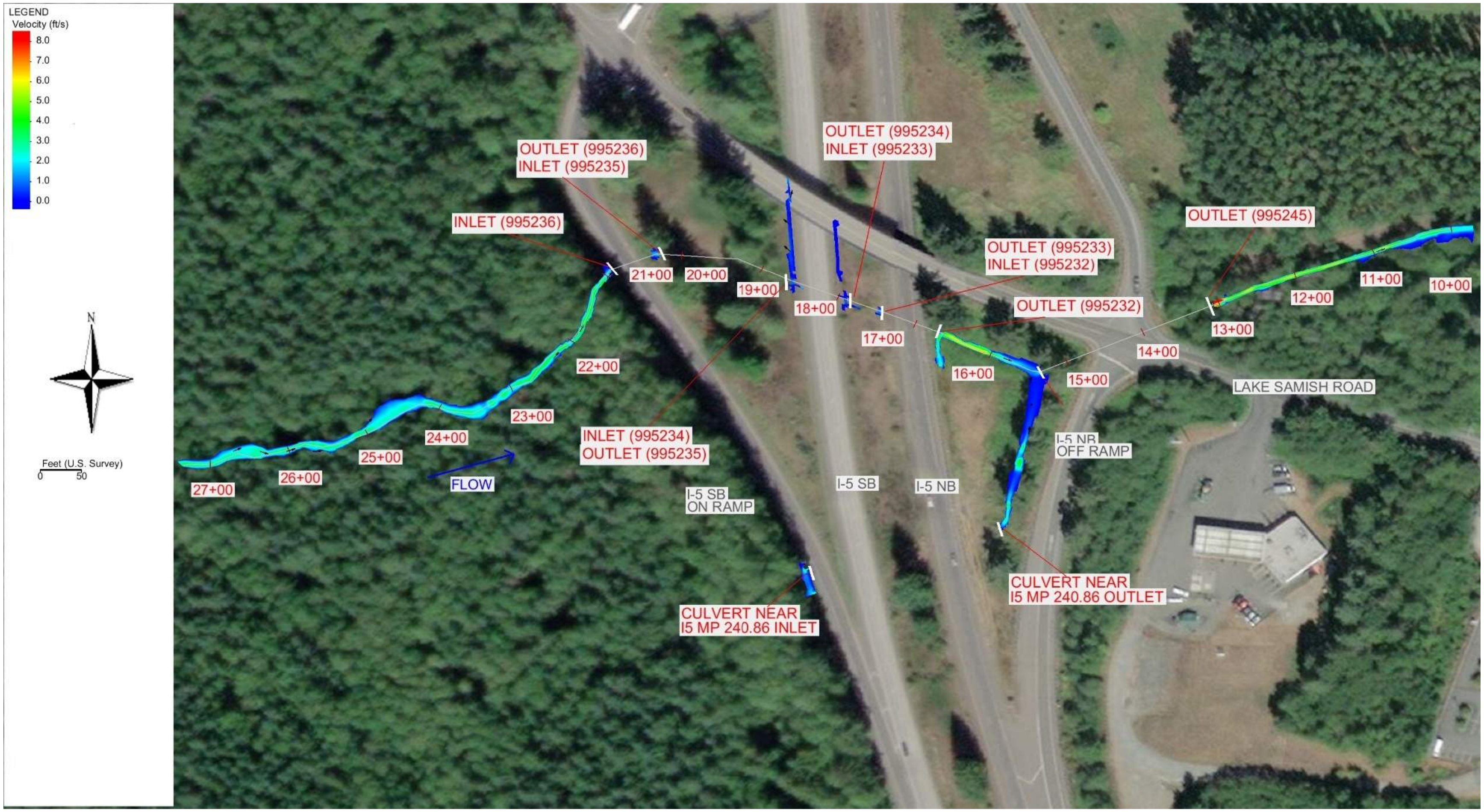
Existing Conditions, 100-Year Flow, Water Surface Elevation (ft)



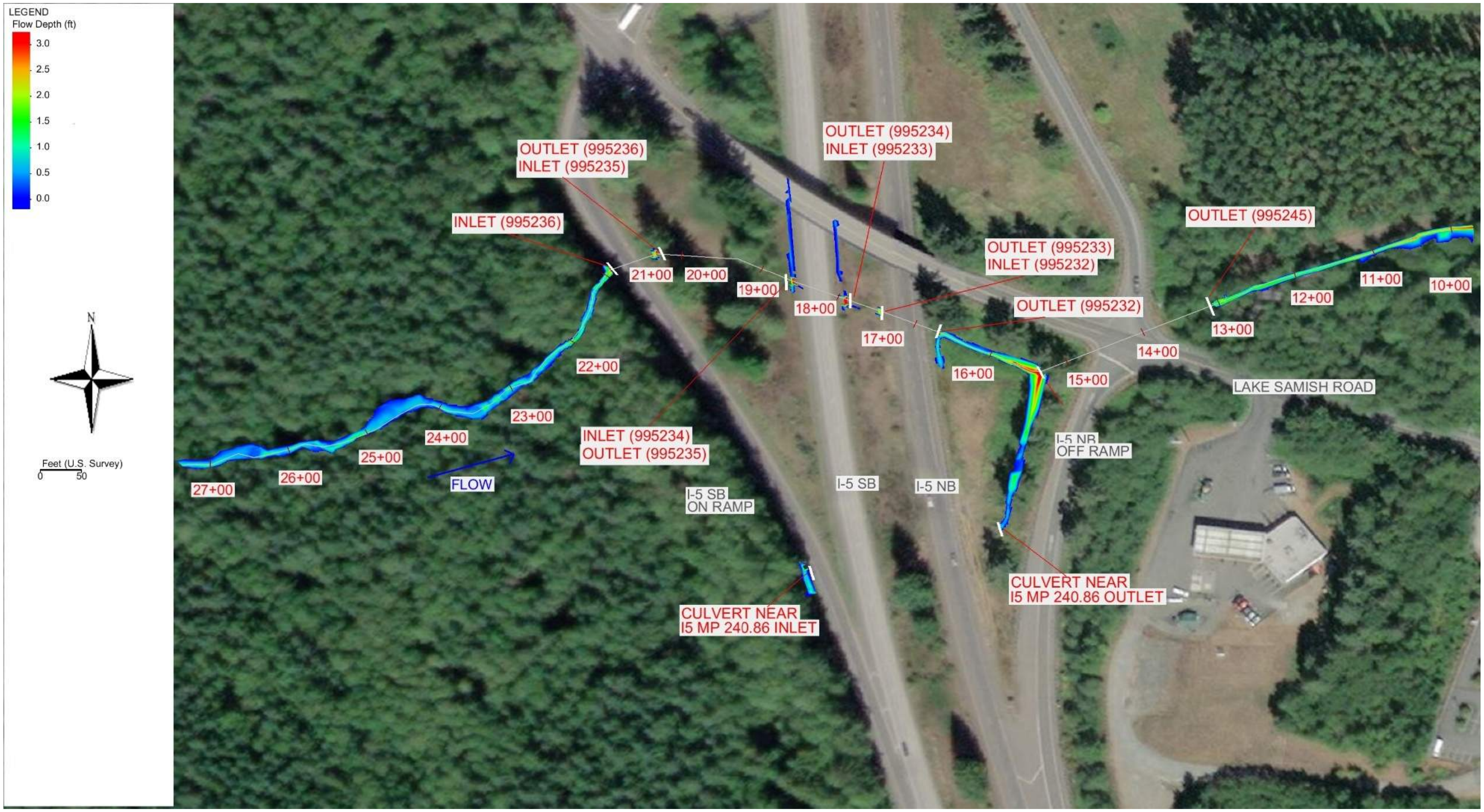
Existing Conditions, 2080 100-Year Flow, Shear Stress (psf)



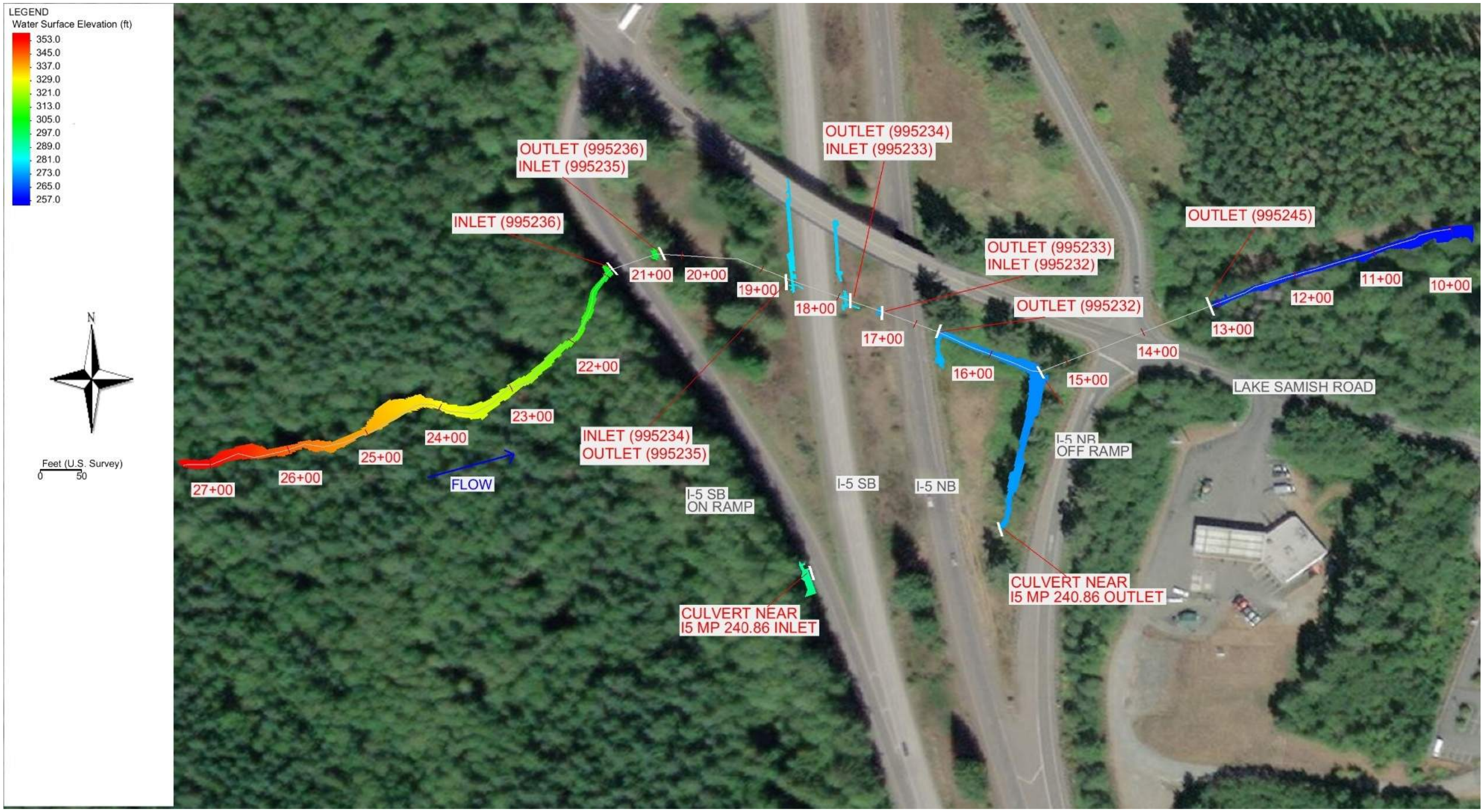
Existing Conditions, 2080 100-Year Flow, Velocity (ft/s)



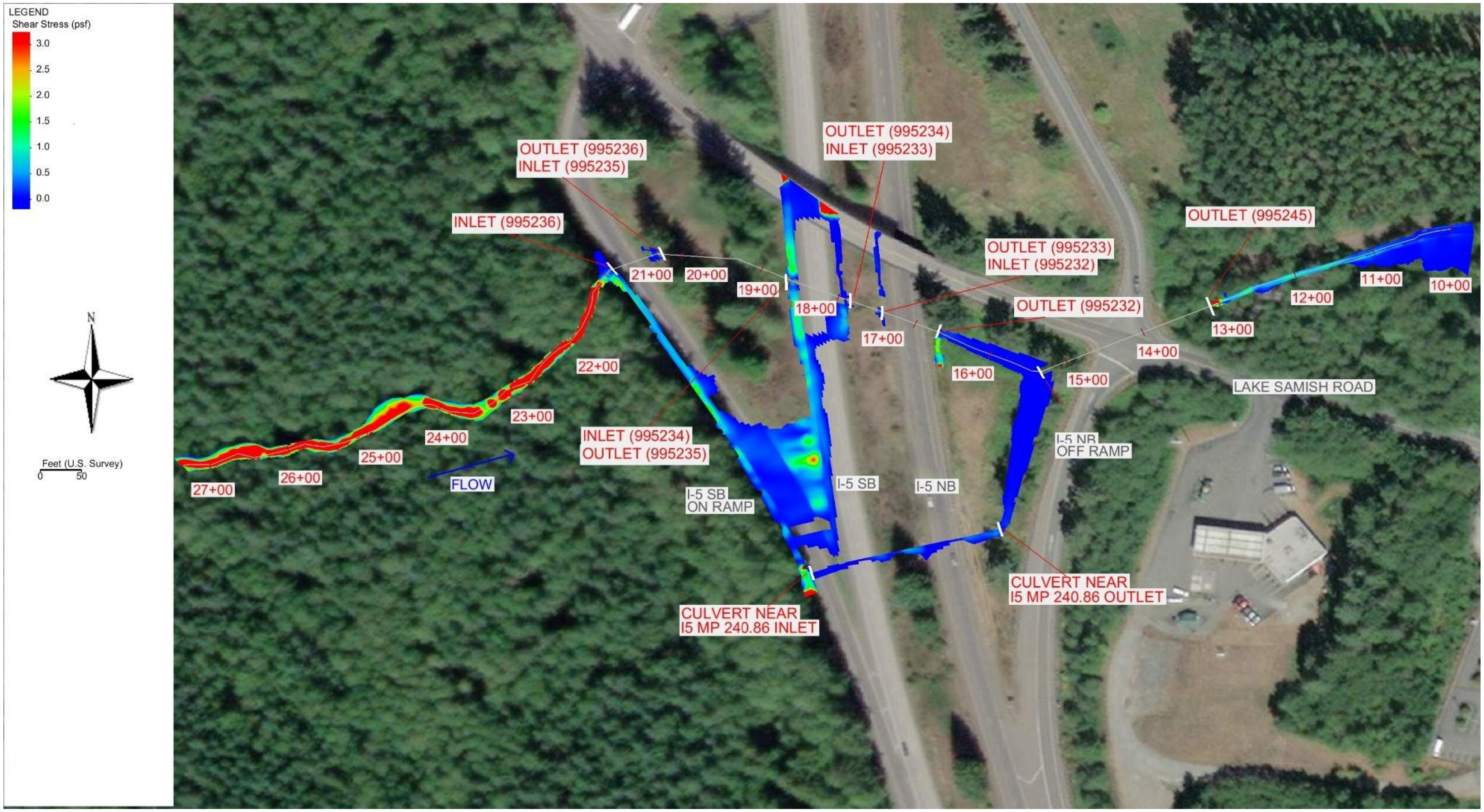
Existing Conditions, 2080 100-Year Flow, Flow Depth (ft)



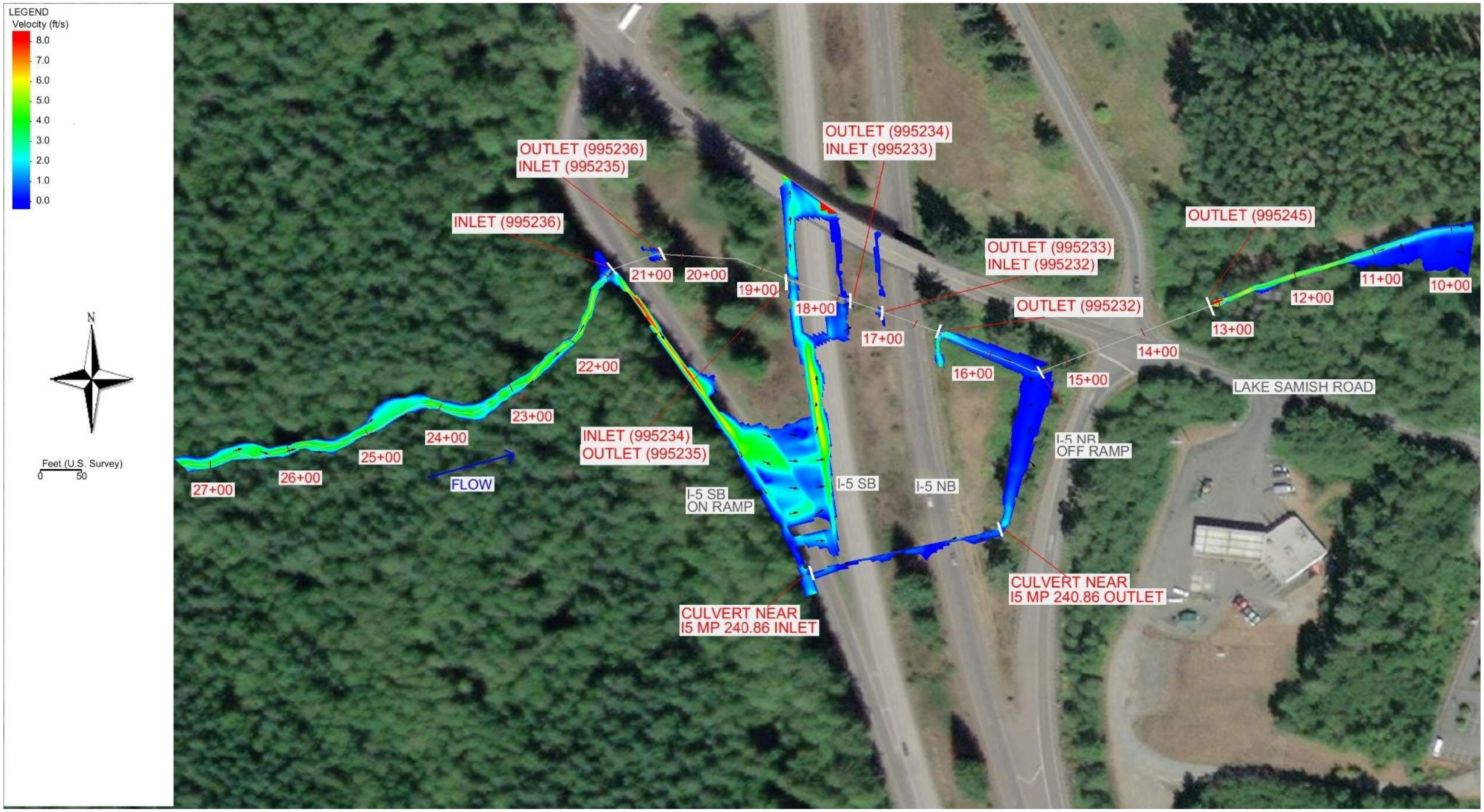
Existing Conditions, 2080 100-Year Flow, Water Surface Elevation (ft)



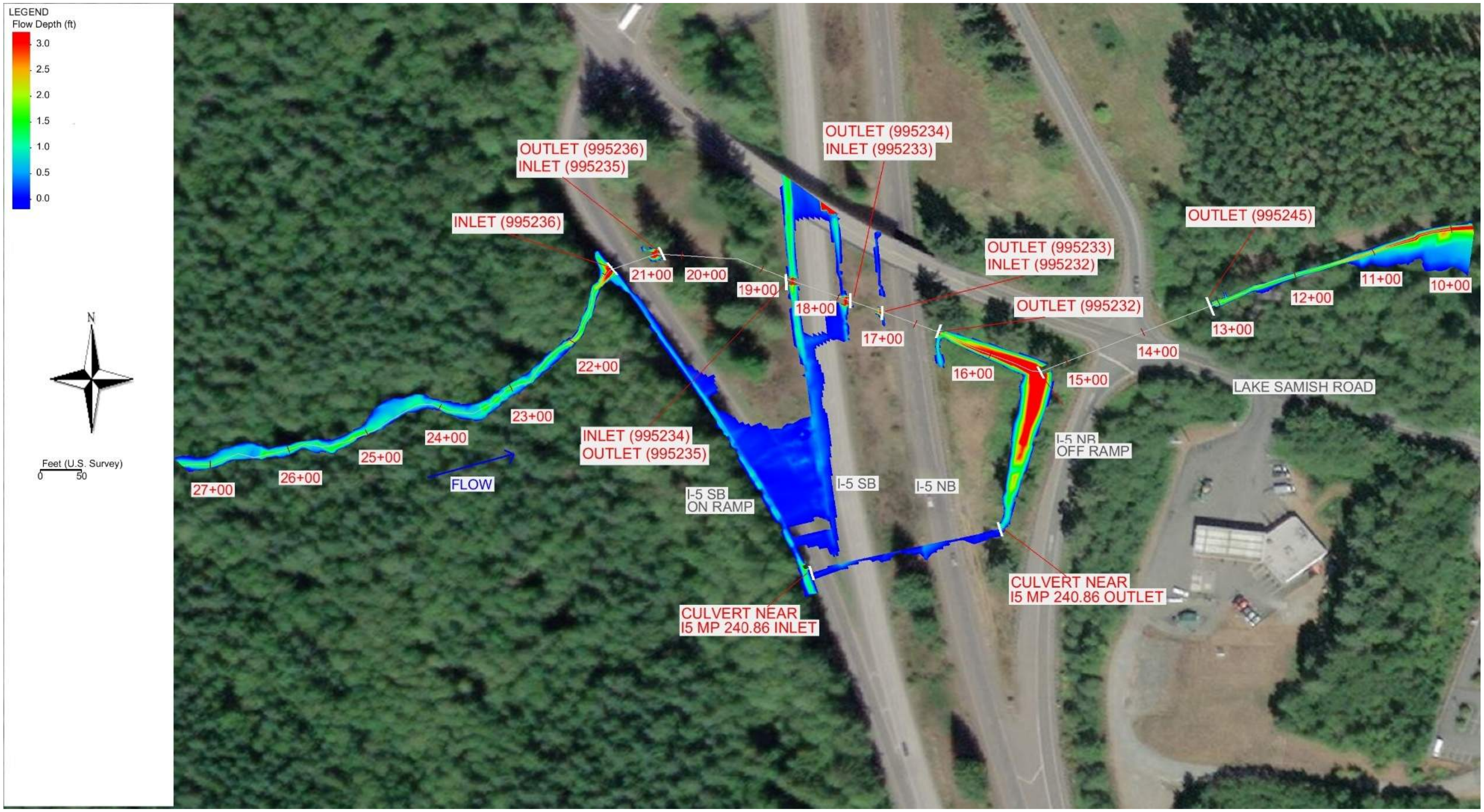
Existing Conditions, 500-Year Flow, Shear Stress (psf)



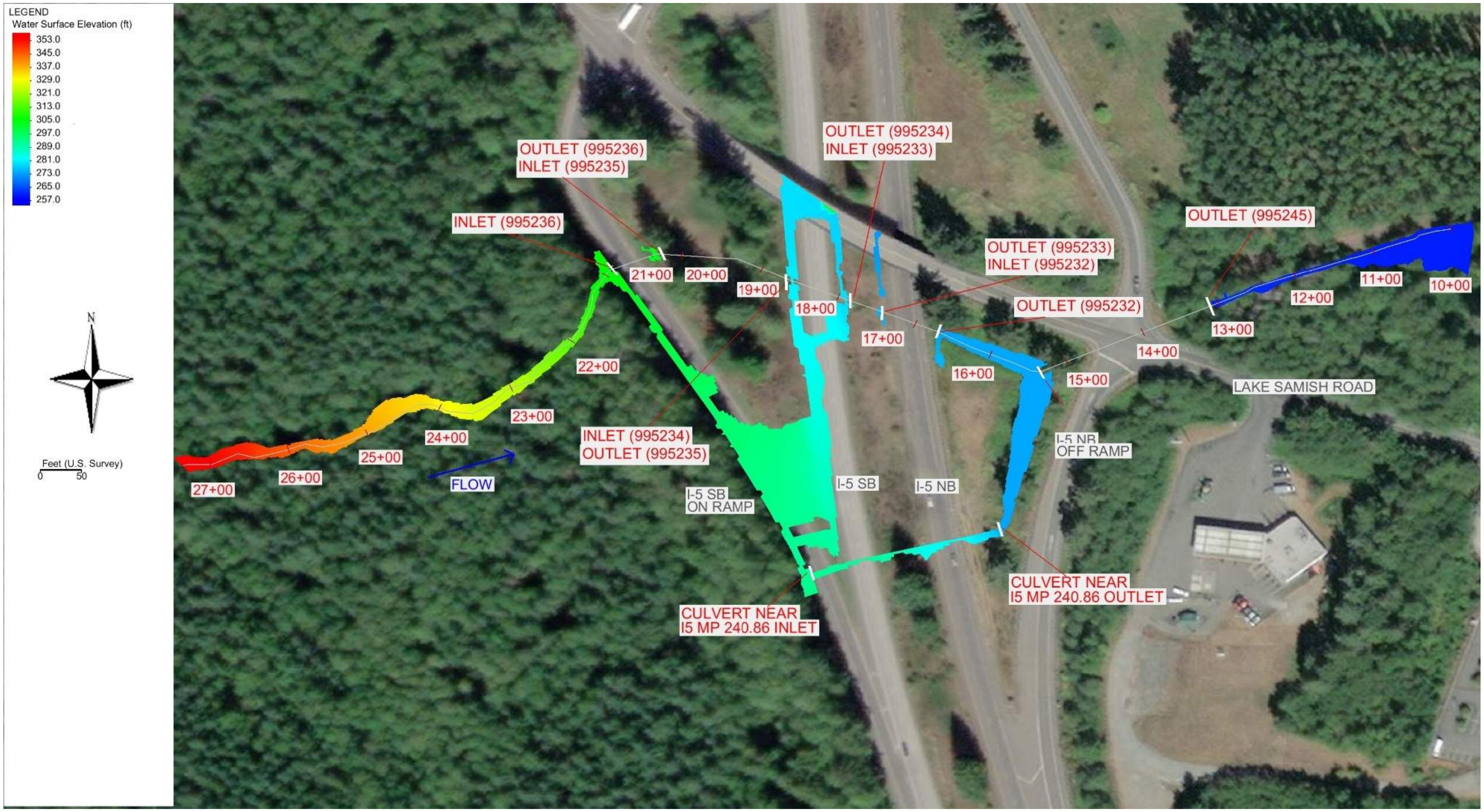
Existing Conditions, 500-Year Flow, Velocity (ft/s)



Existing Conditions, 500-Year Flow, Flow Depth (ft)

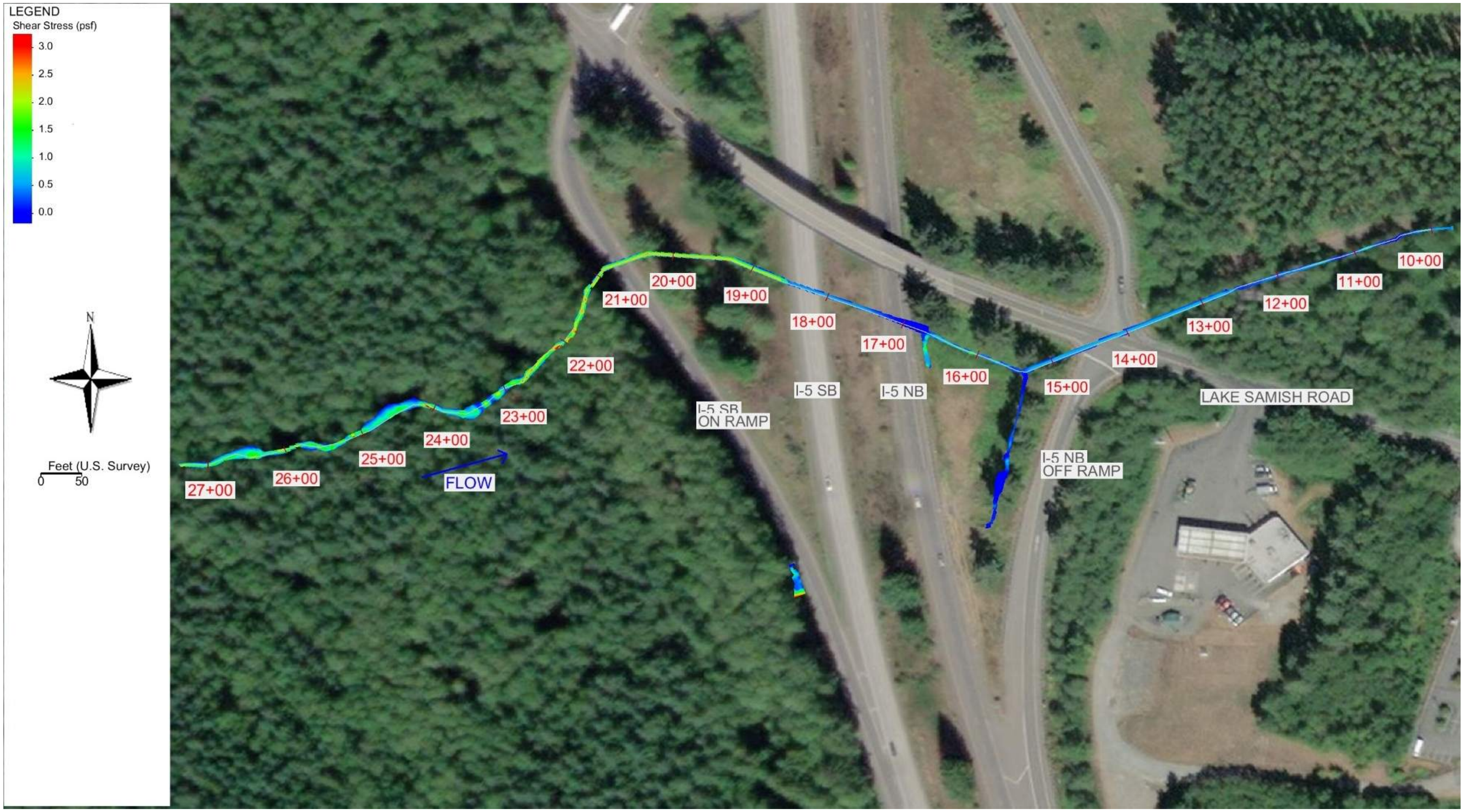


Existing Conditions, 500-Year Flow, Water Surface Elevation (ft)

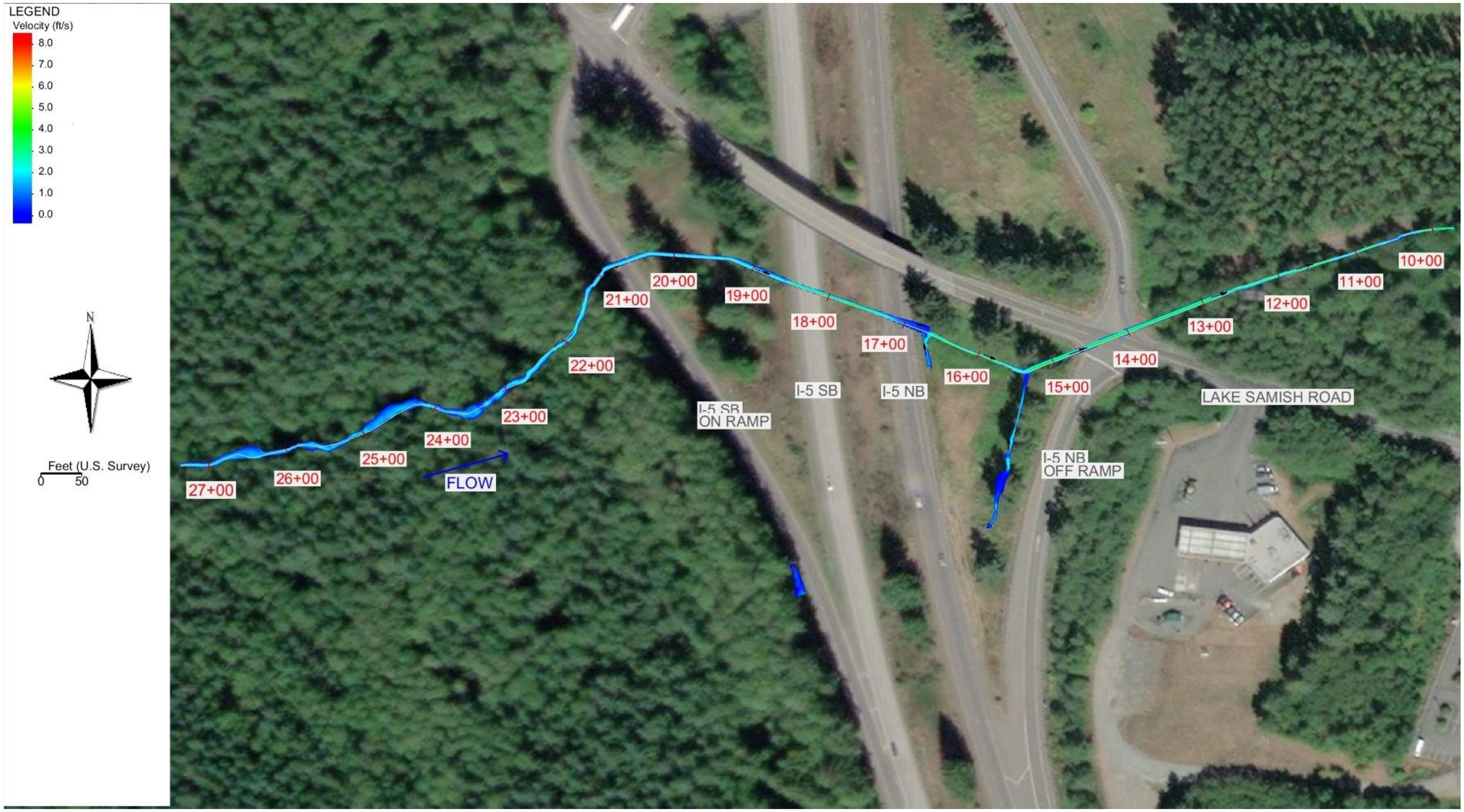


Natural Conditions Model Water Surface Profiles

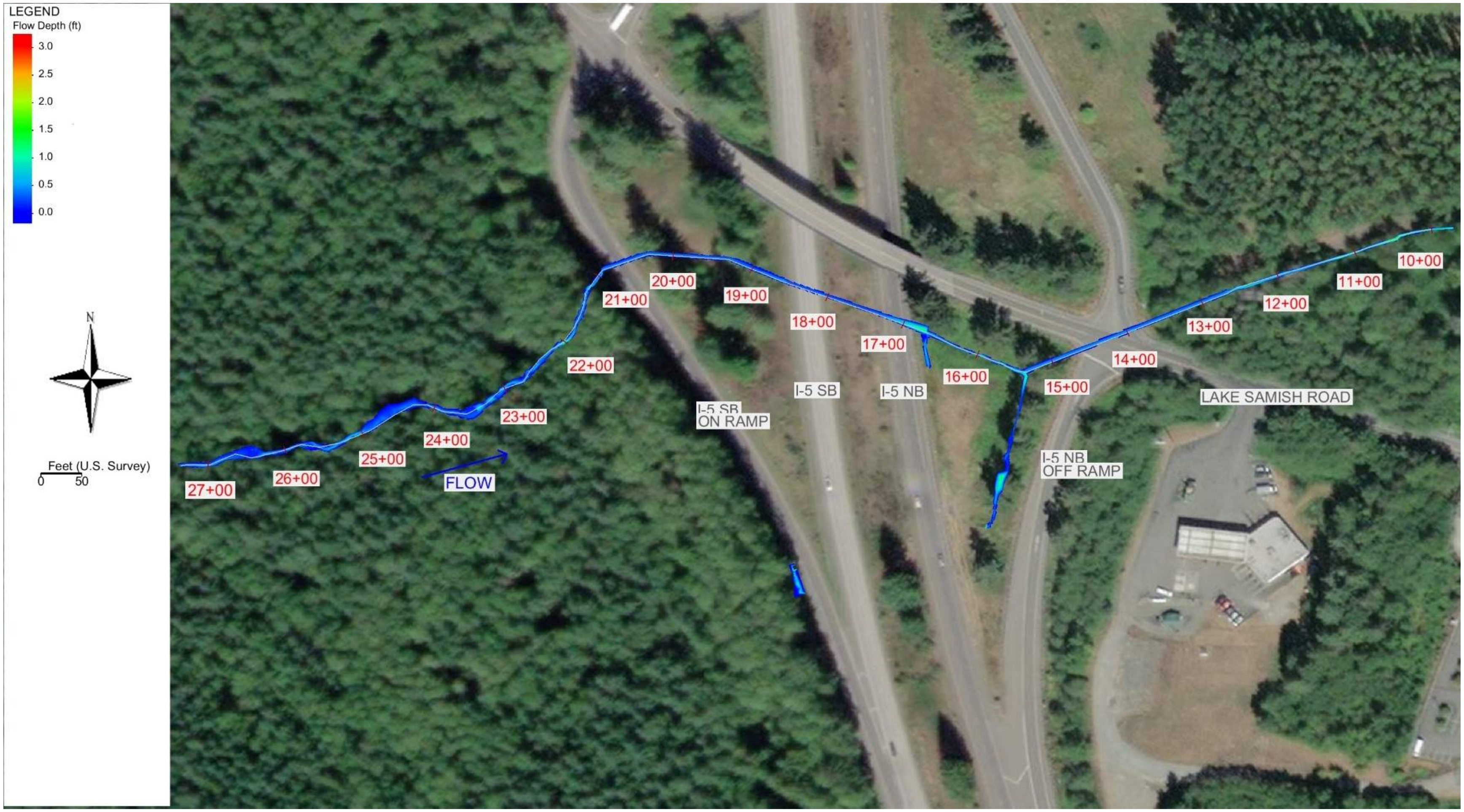
Natural Conditions, 2-Year Flow, Shear Stress (psf)



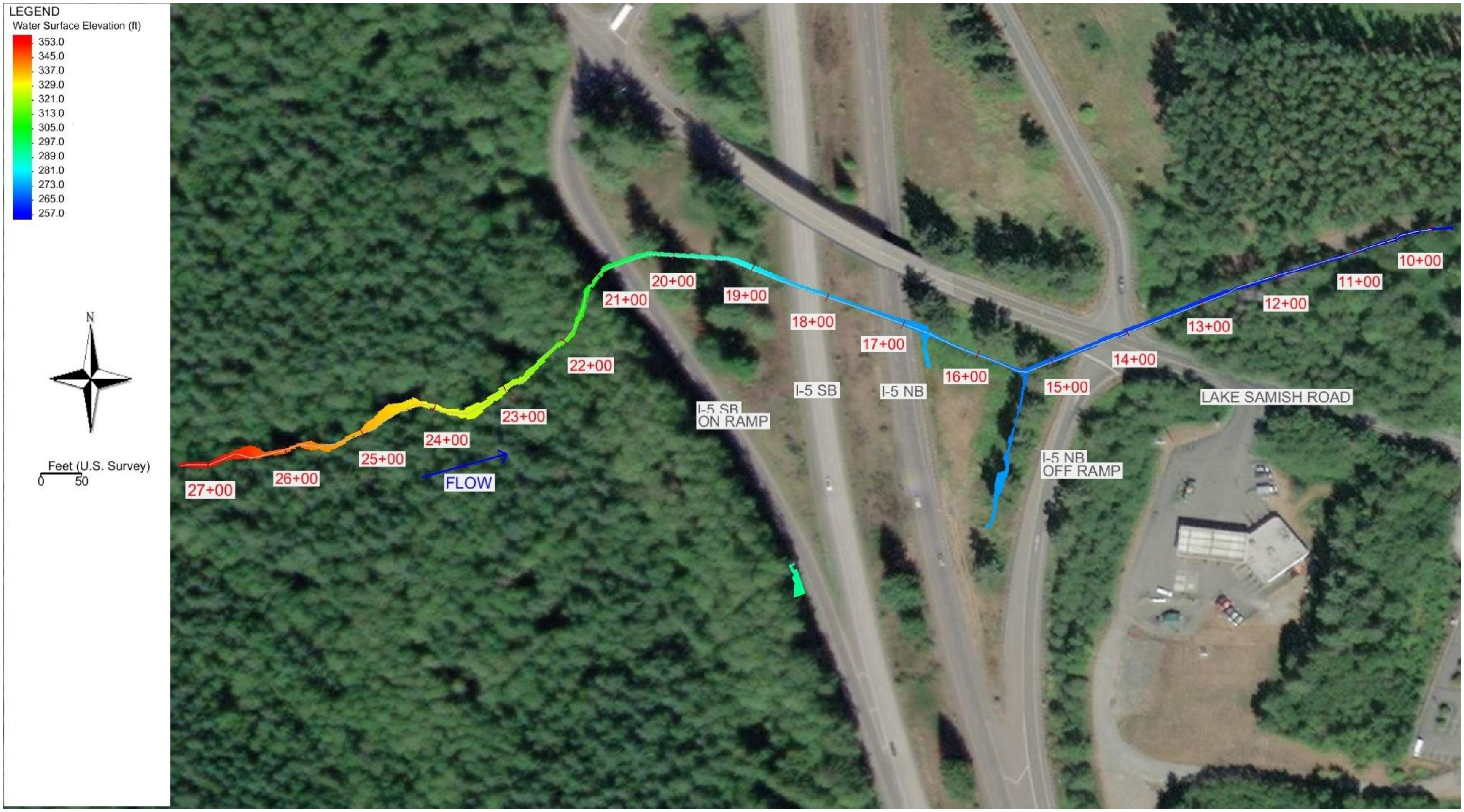
Natural Conditions, 2-Year Flow, Velocity (ft/s)



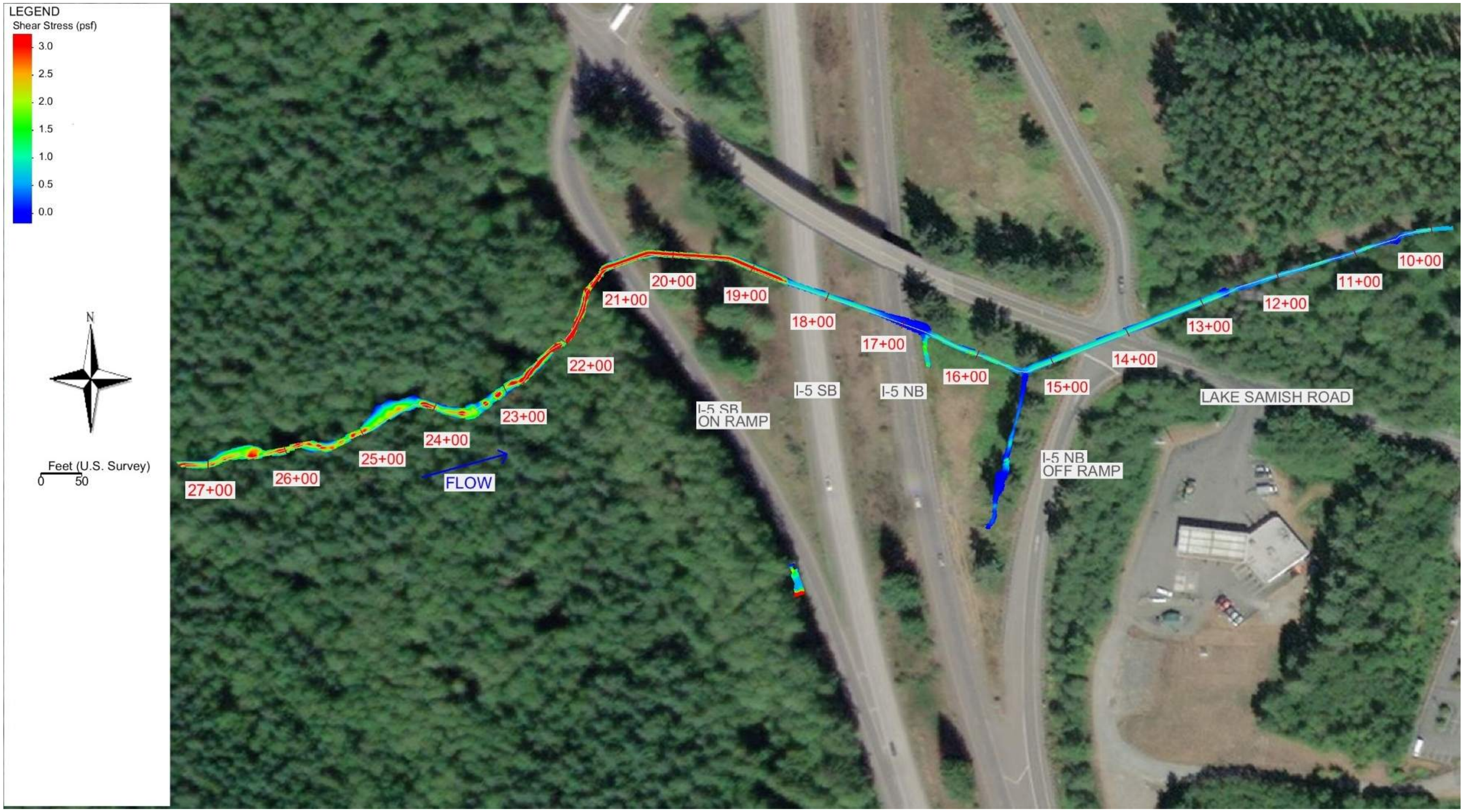
Natural Conditions, 2-Year Flow, Flow Depth (ft)



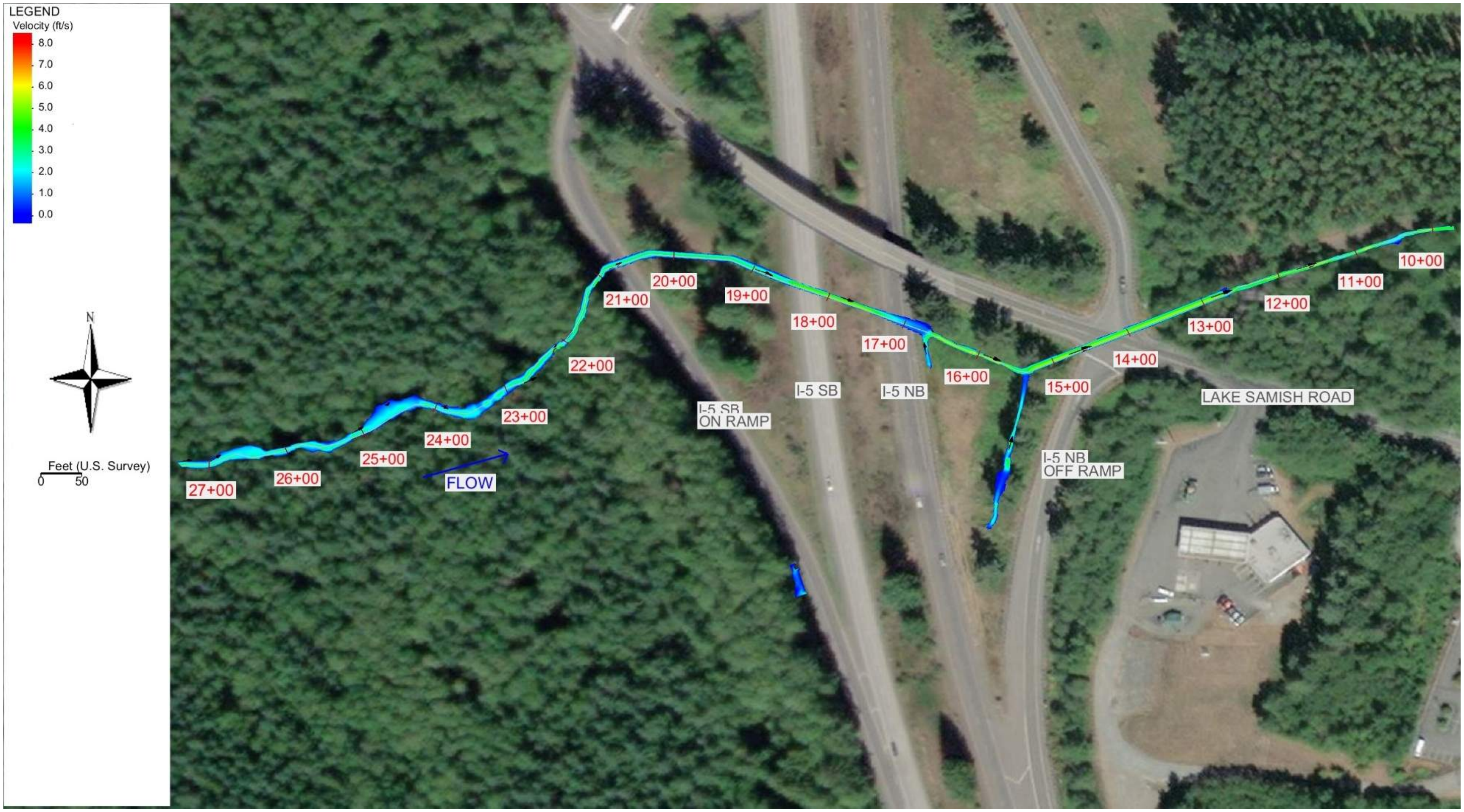
Natural Conditions, 2-Year Flow, Water Surface Elevation (ft)



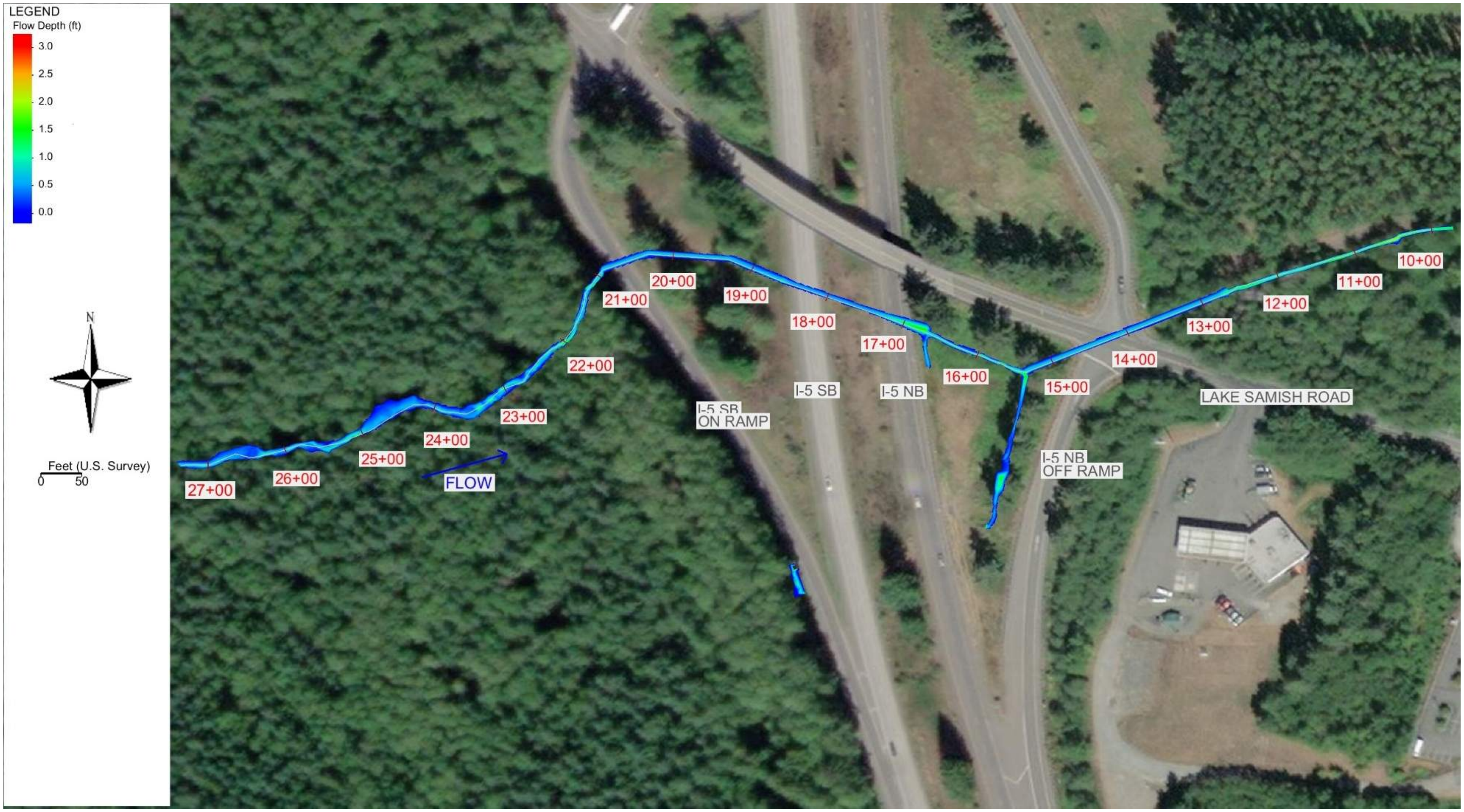
Natural Conditions, 25-Year Flow, Shear Stress (psf)



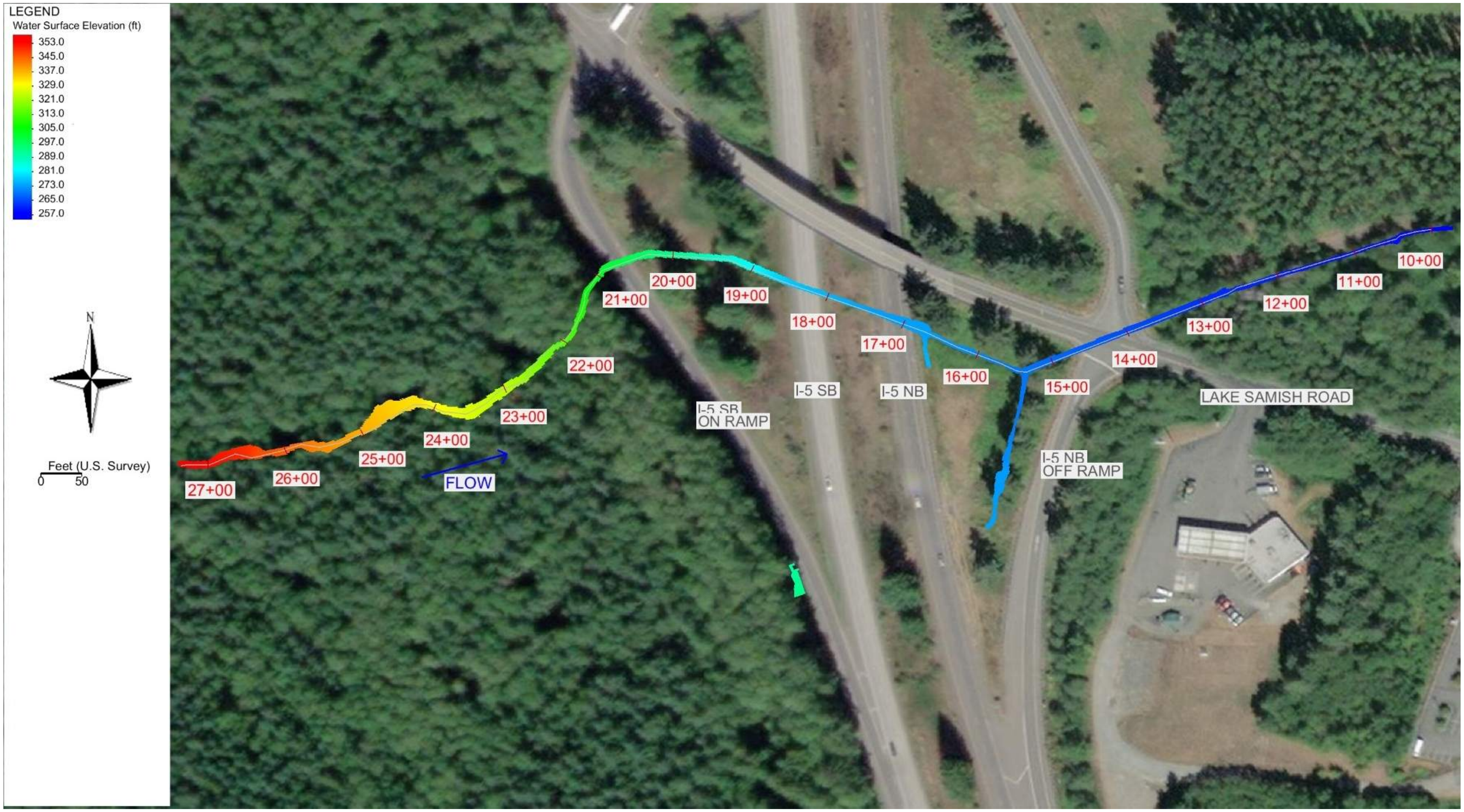
Natural Conditions, 25-Year Flow, Velocity (ft/s)



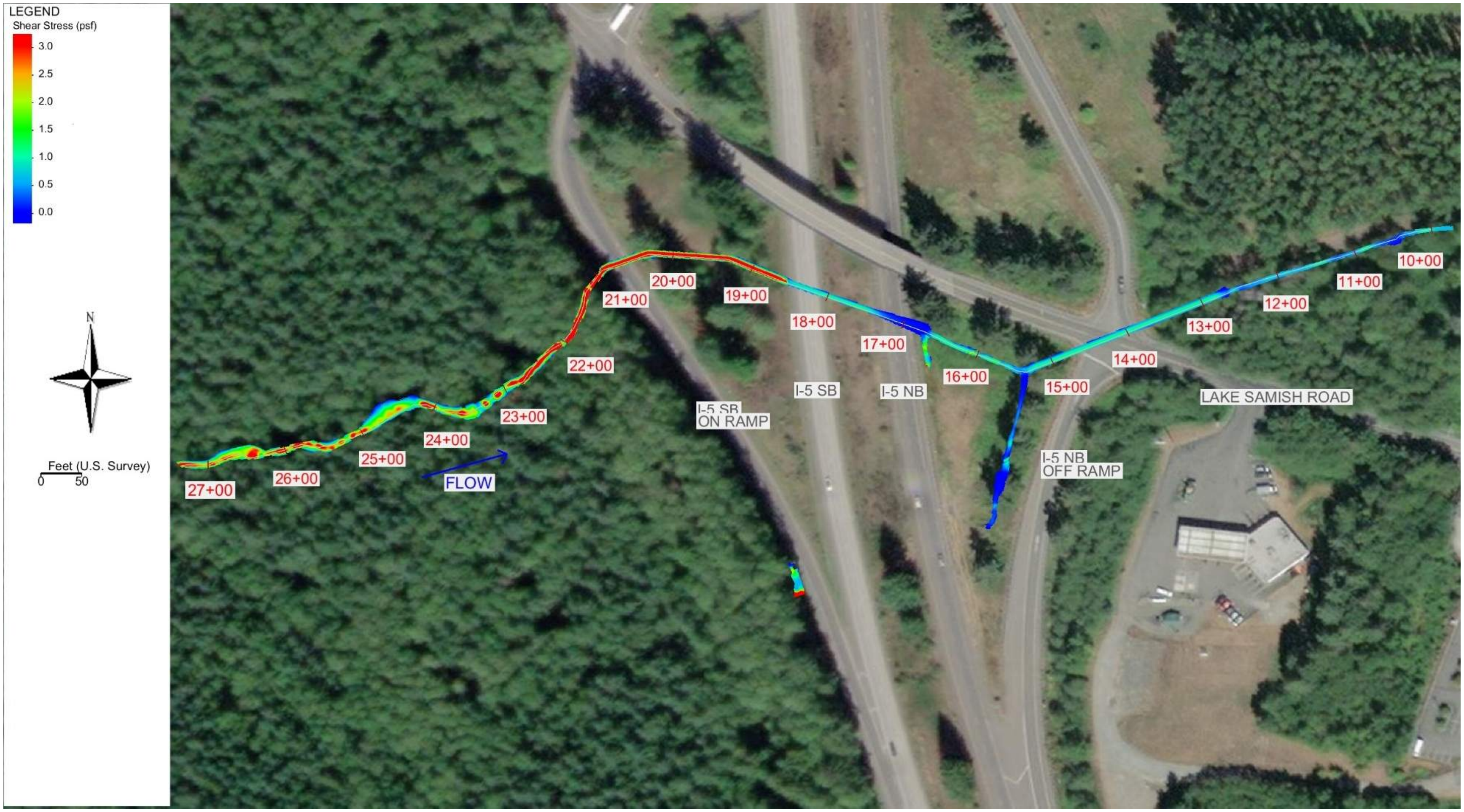
Natural Conditions, 25-Year Flow, Flow Depth (ft)



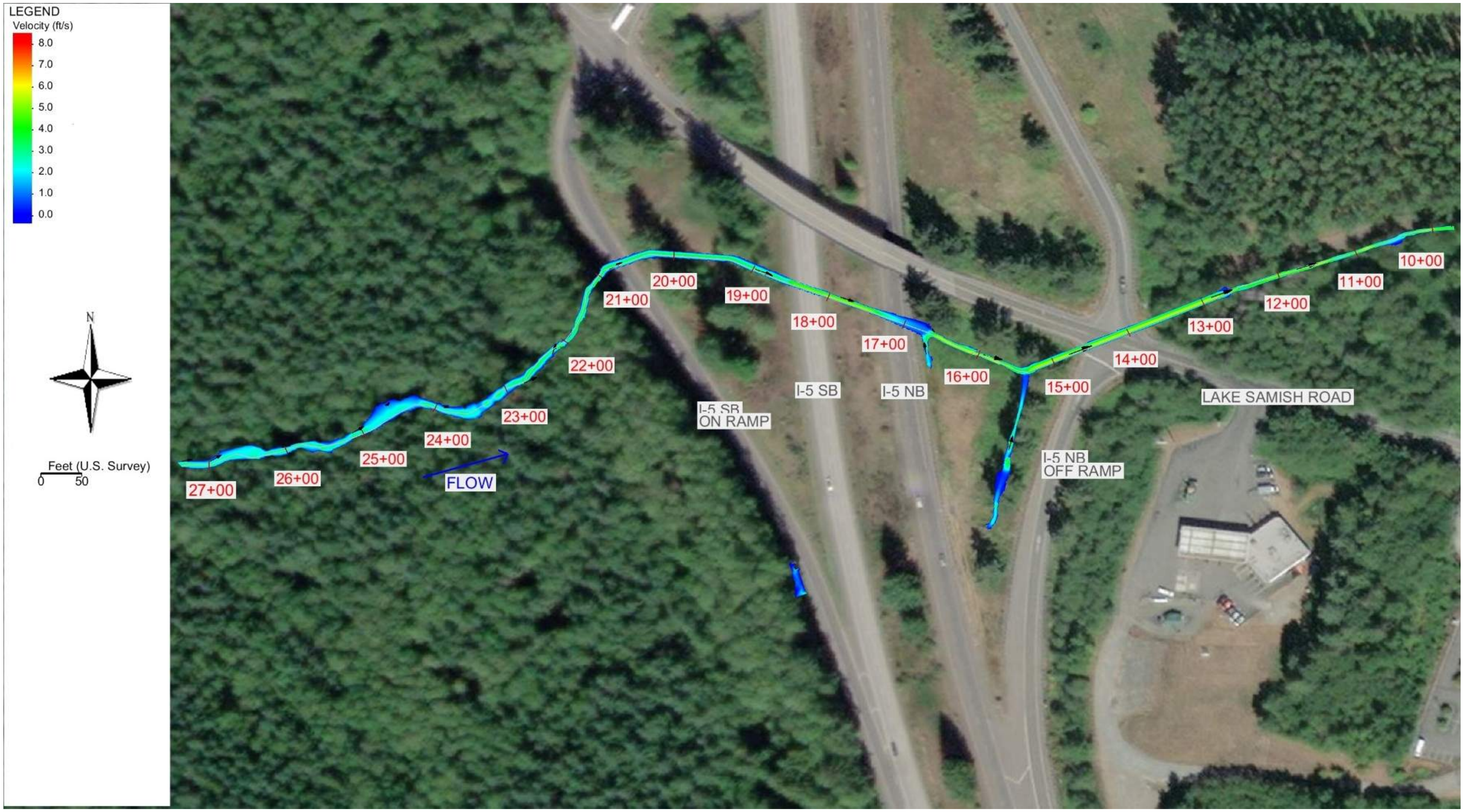
Natural Conditions, 25-Year Flow, Water Surface Elevation (ft)



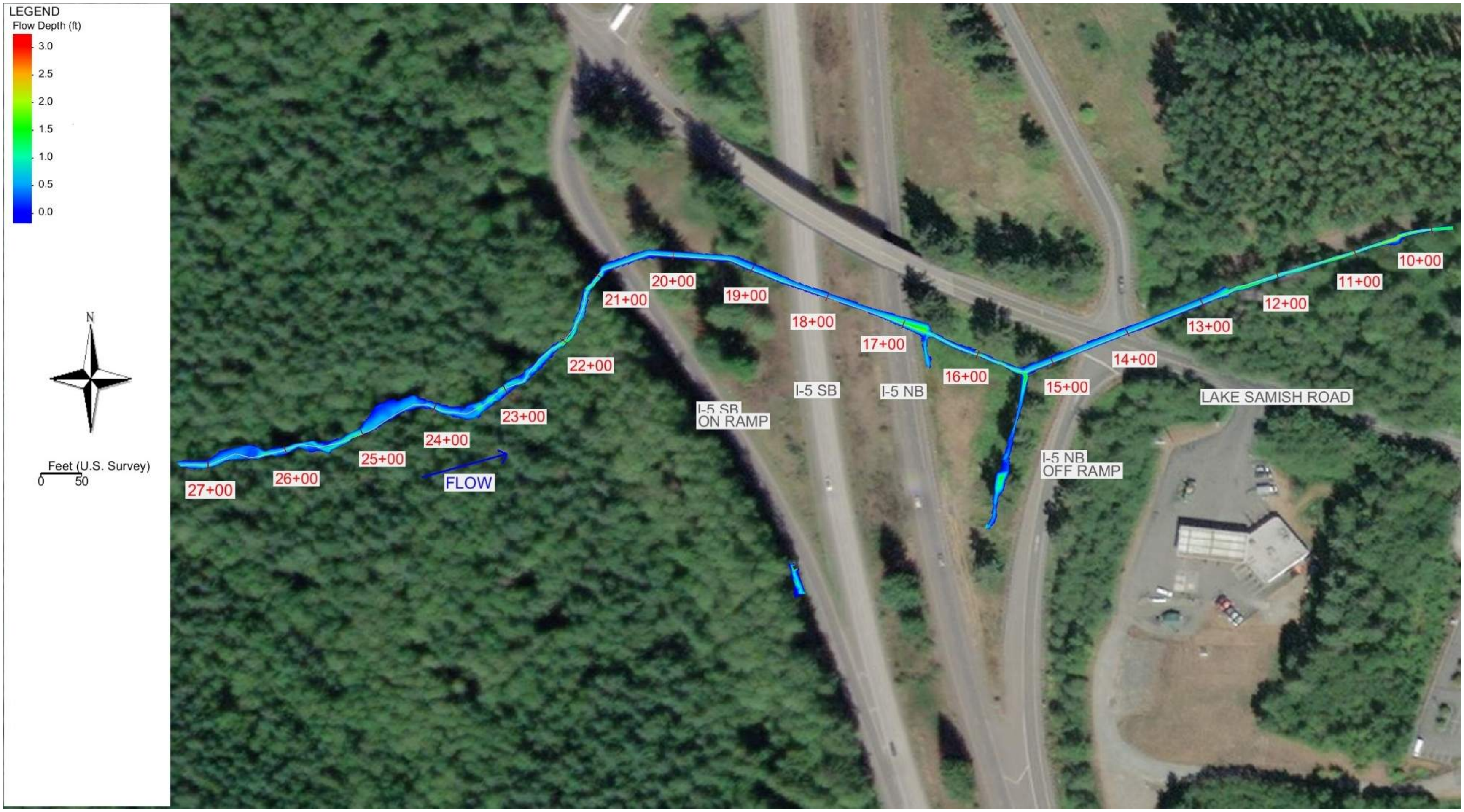
Natural Conditions, 50-Year Flow, Shear Stress (psf)



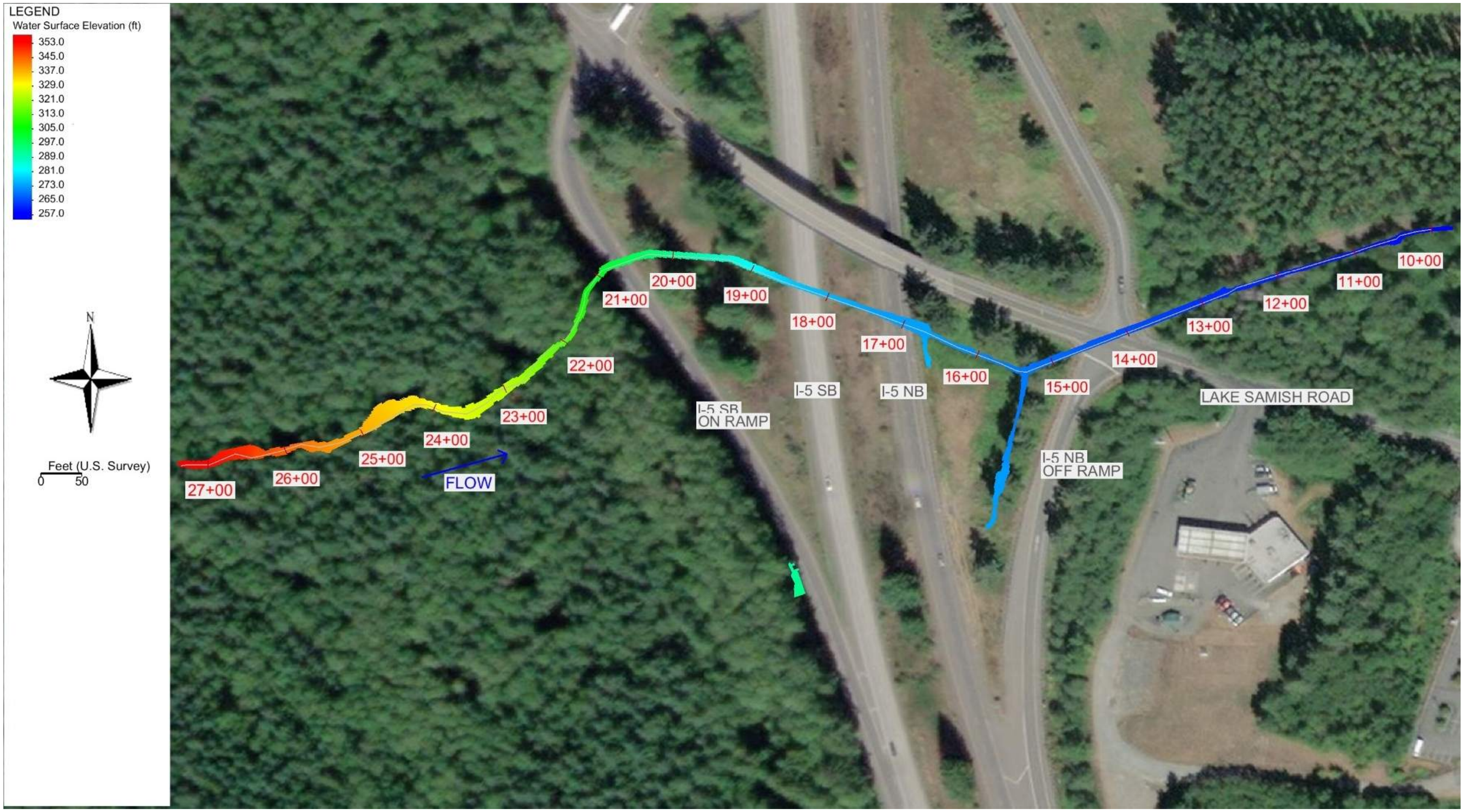
Natural Conditions, 50-Year Flow, Velocity (ft/s)



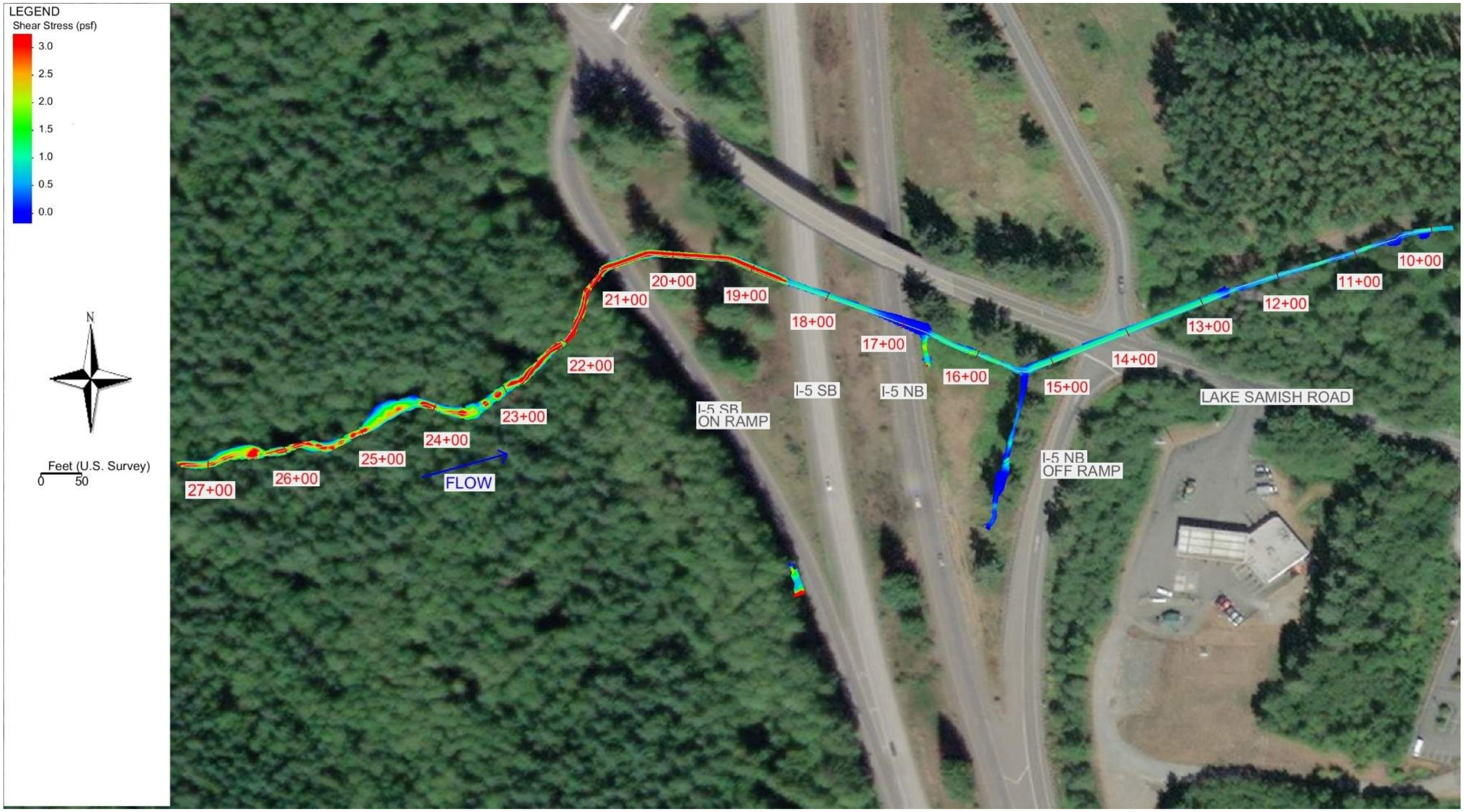
Natural Conditions, 50-Year Flow, Flow Depth (ft)



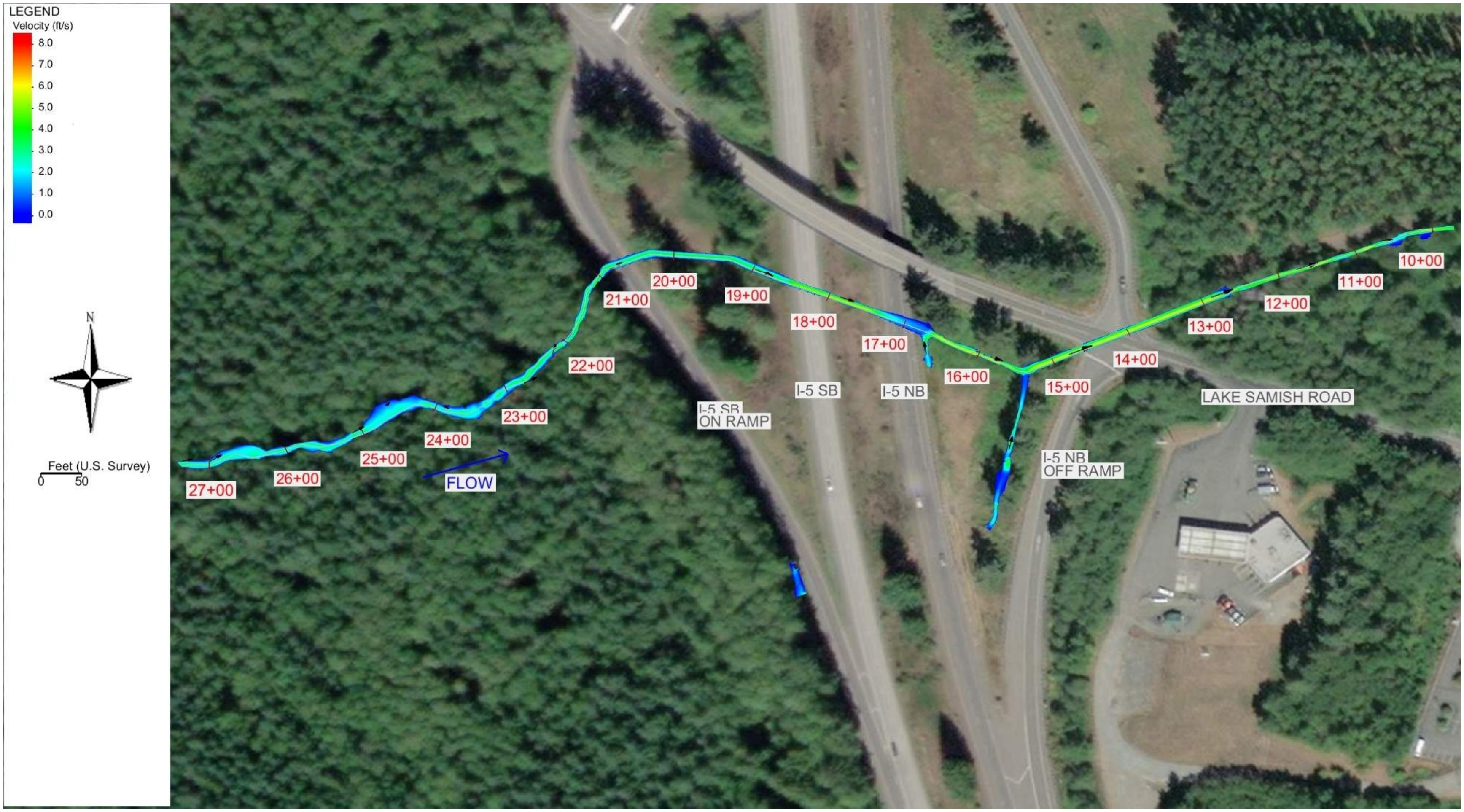
Natural Conditions, 50-Year Flow, Water Surface Elevation (ft)



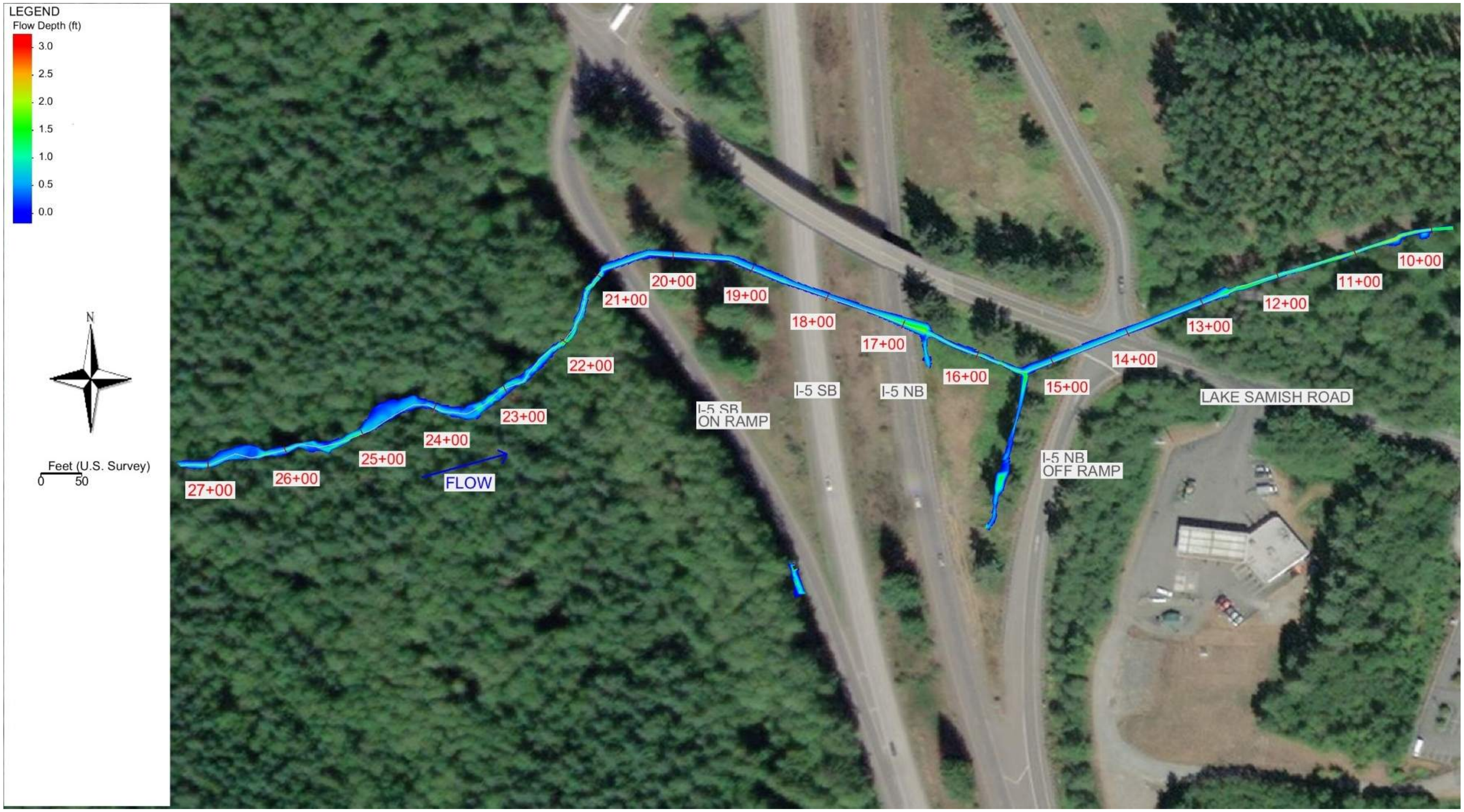
Natural Conditions, 100-Year Flow, Shear Stress (psf)



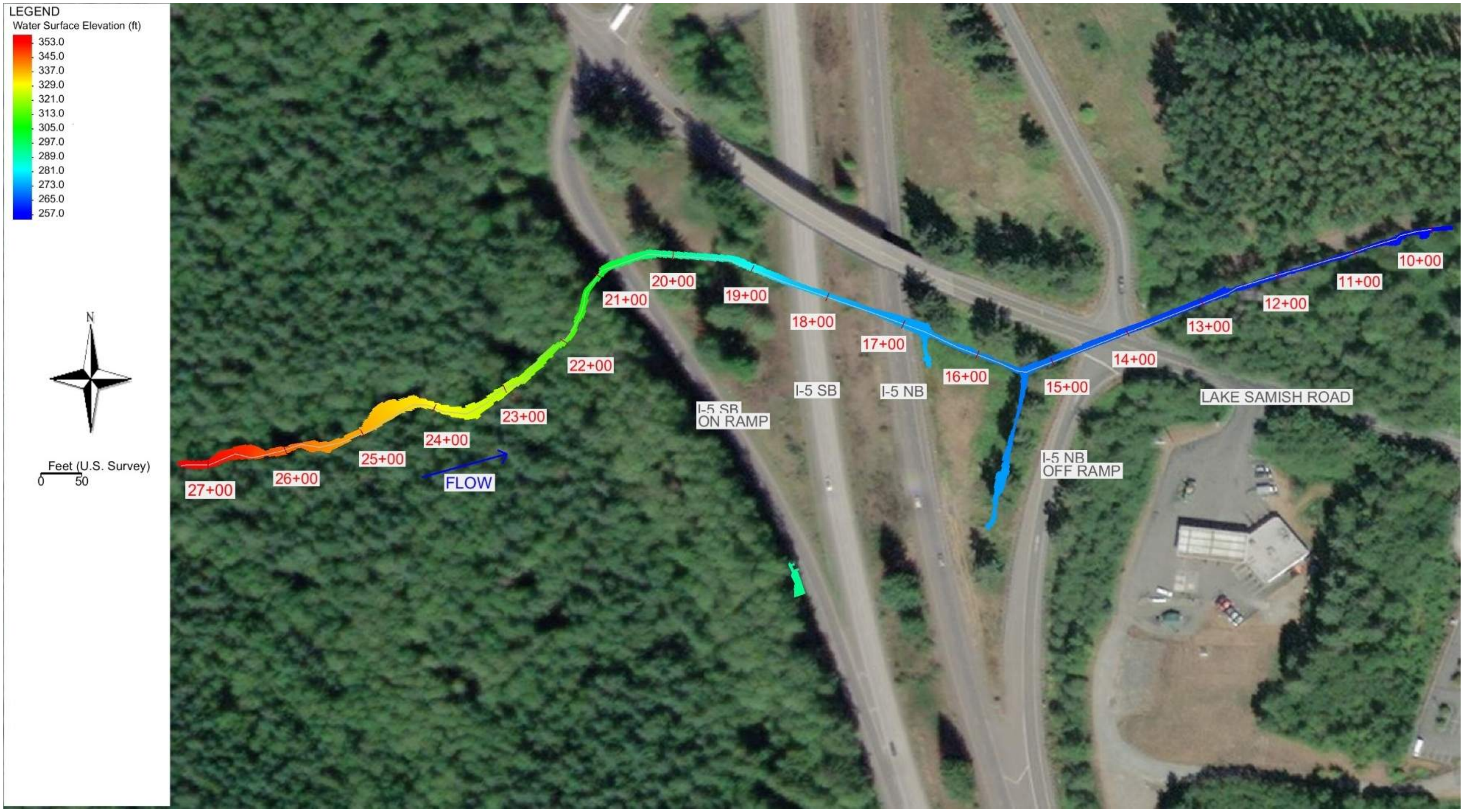
Natural Conditions, 100-Year Flow, Velocity (ft/s)



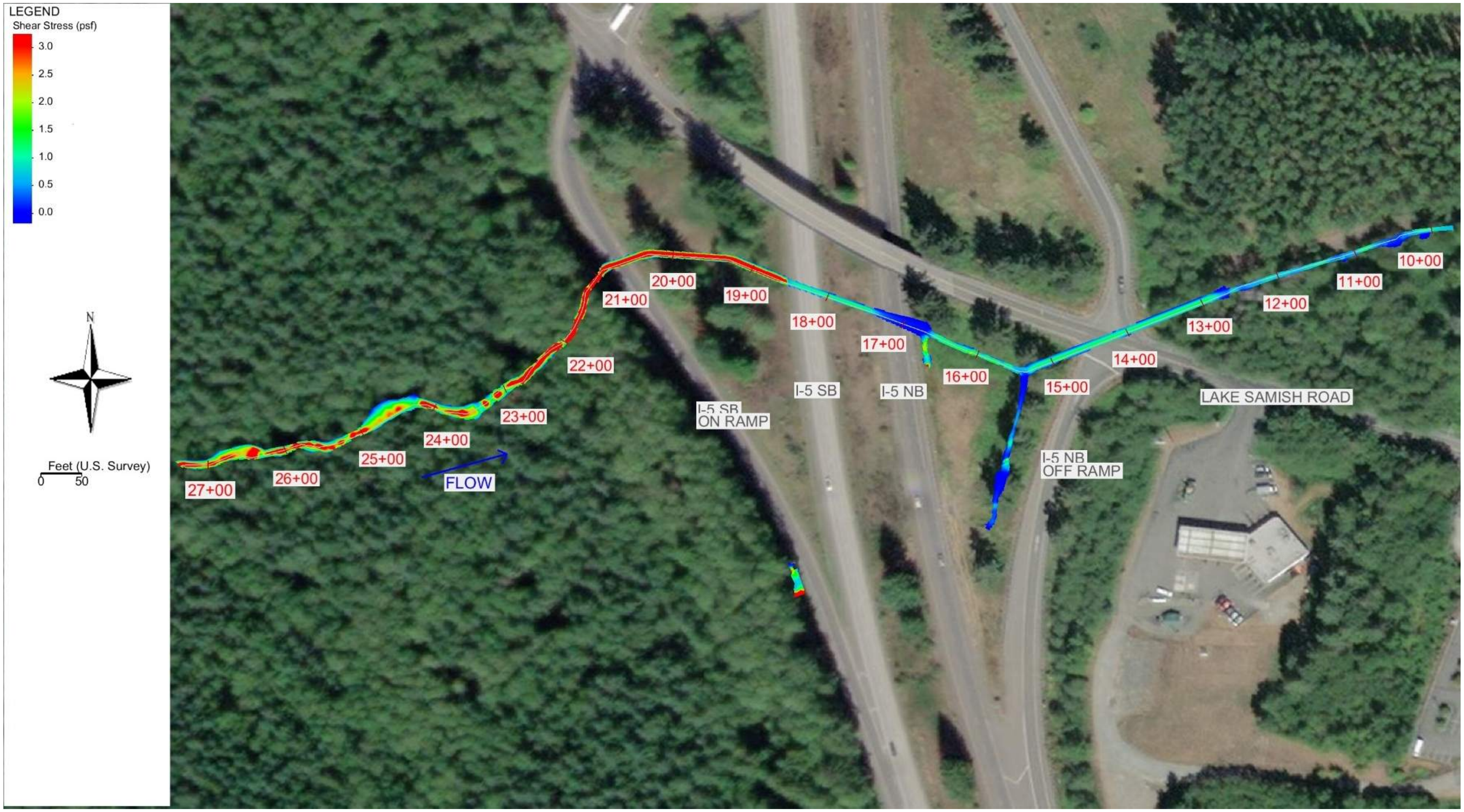
Natural Conditions, 100-Year Flow, Flow Depth (ft)



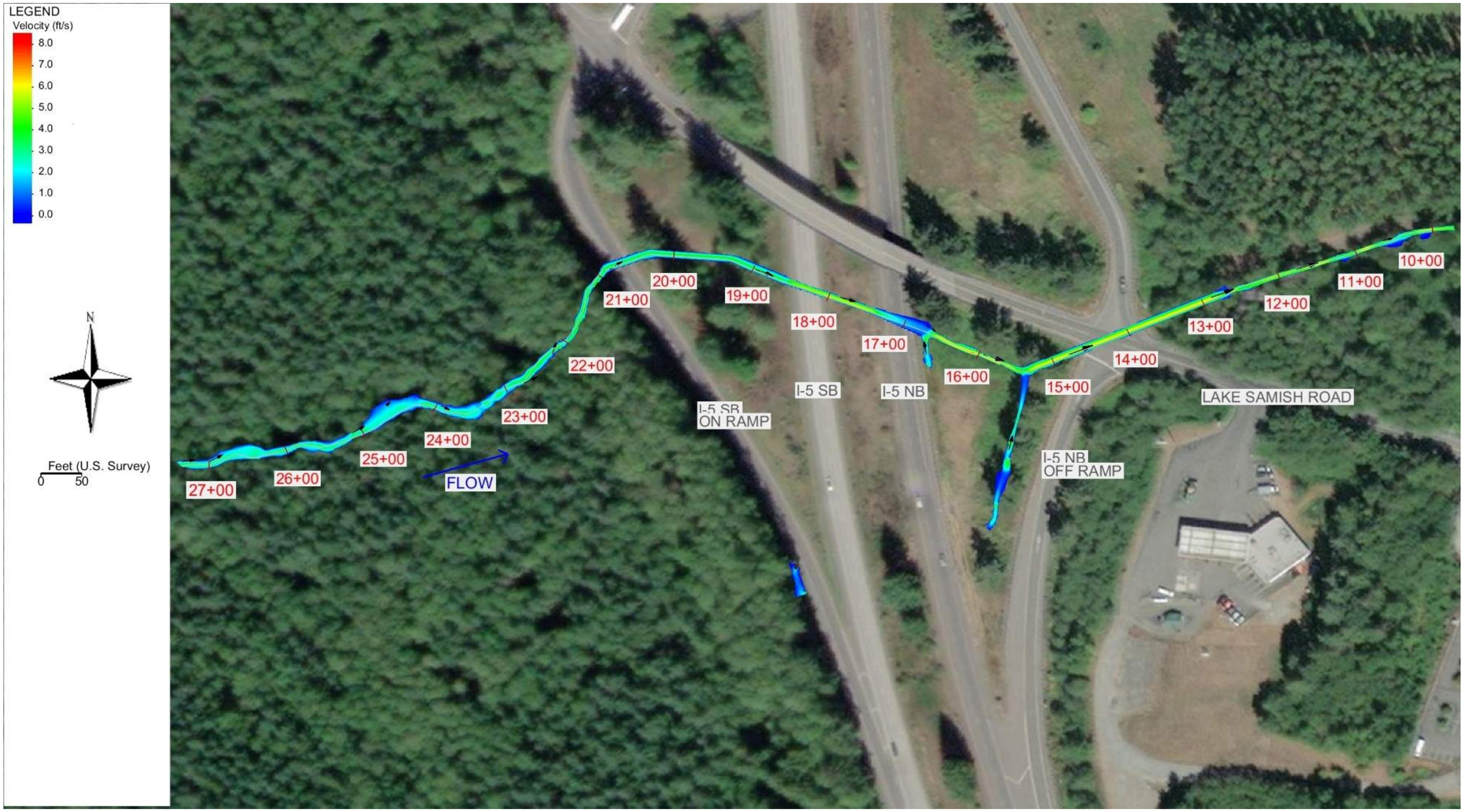
Natural Conditions, 100-Year Flow, Water Surface Elevation (ft)



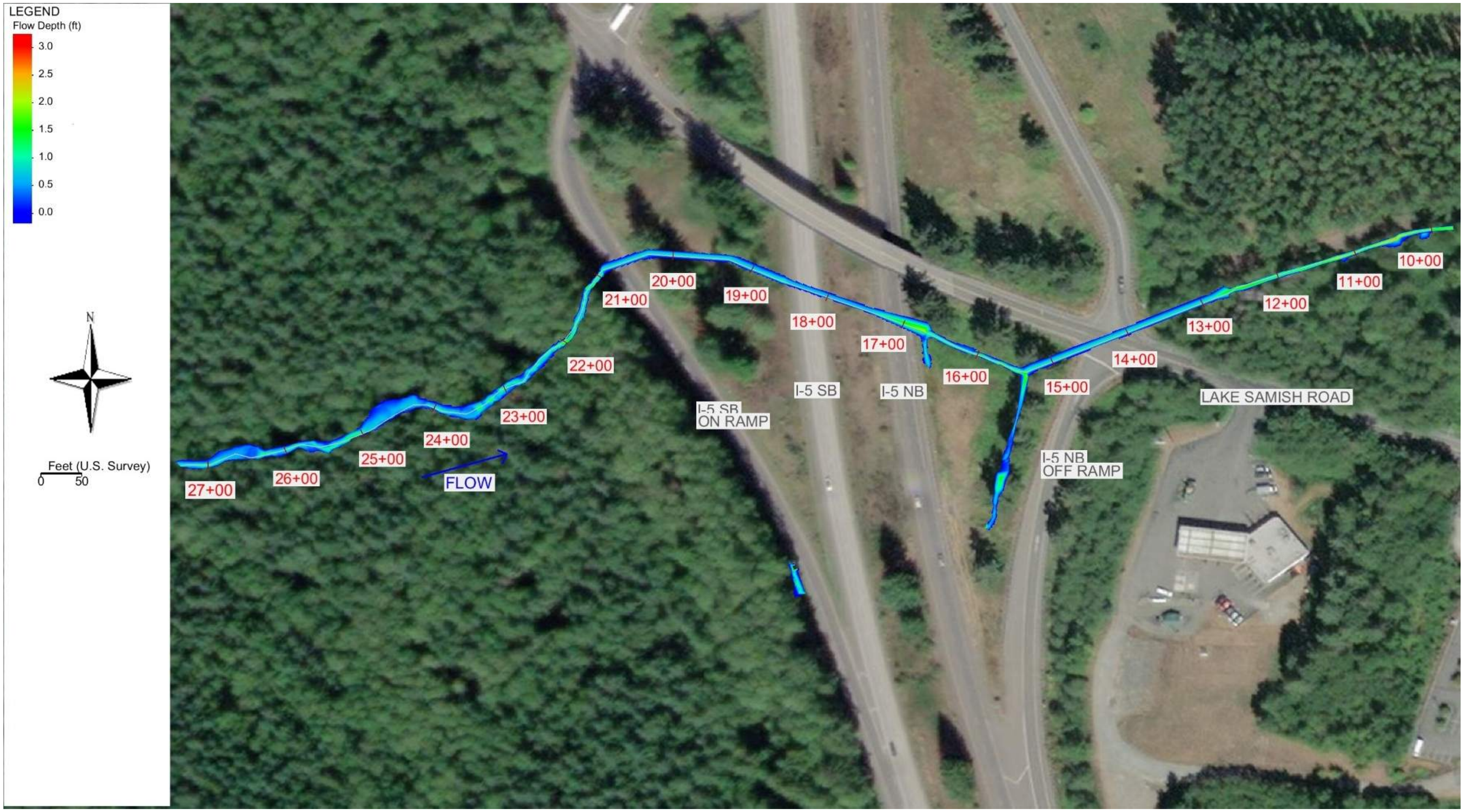
Natural Conditions, 2080 100-Year Flow, Shear Stress (psf)



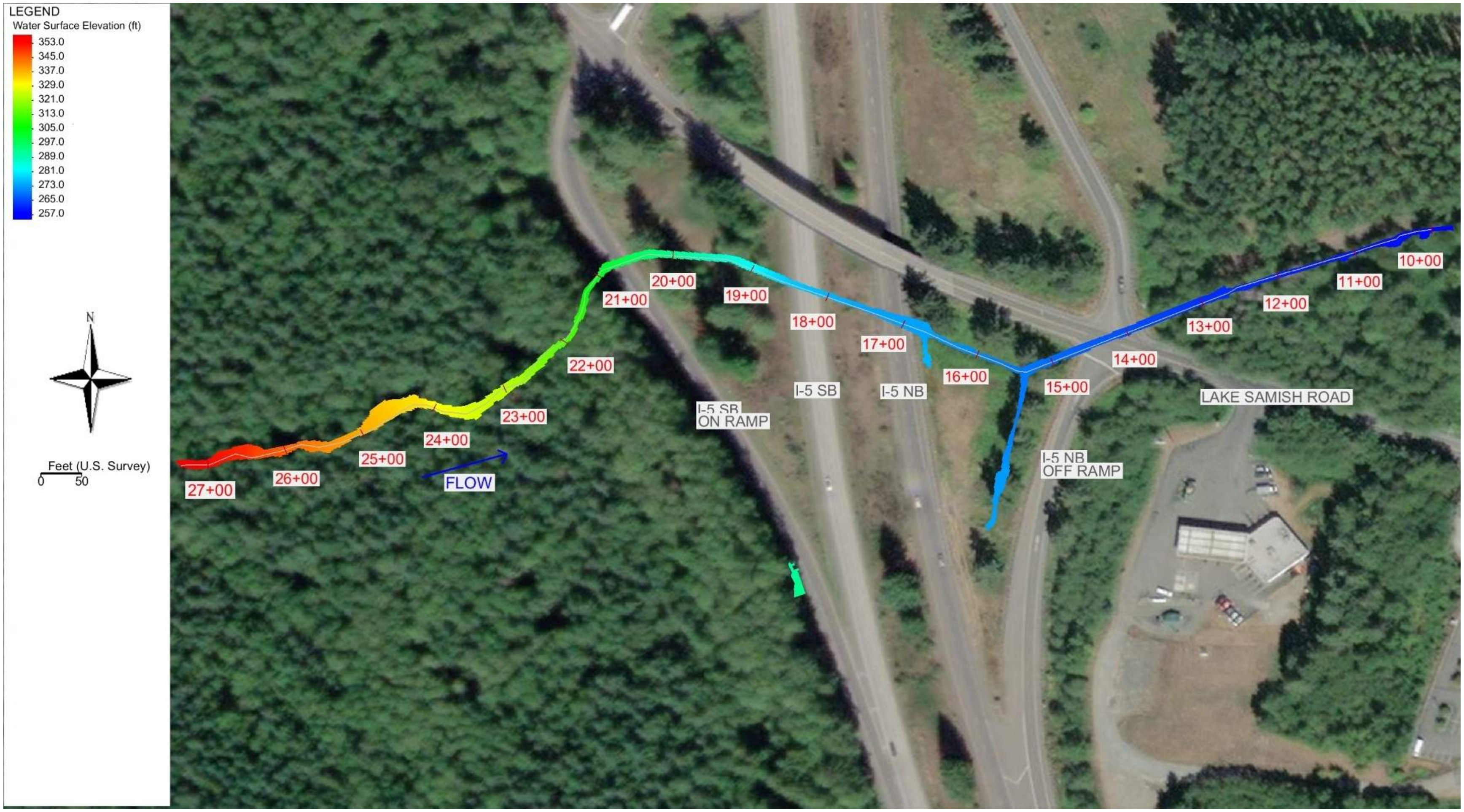
Natural Conditions, 2080 100-Year Flow, Velocity (ft/s)



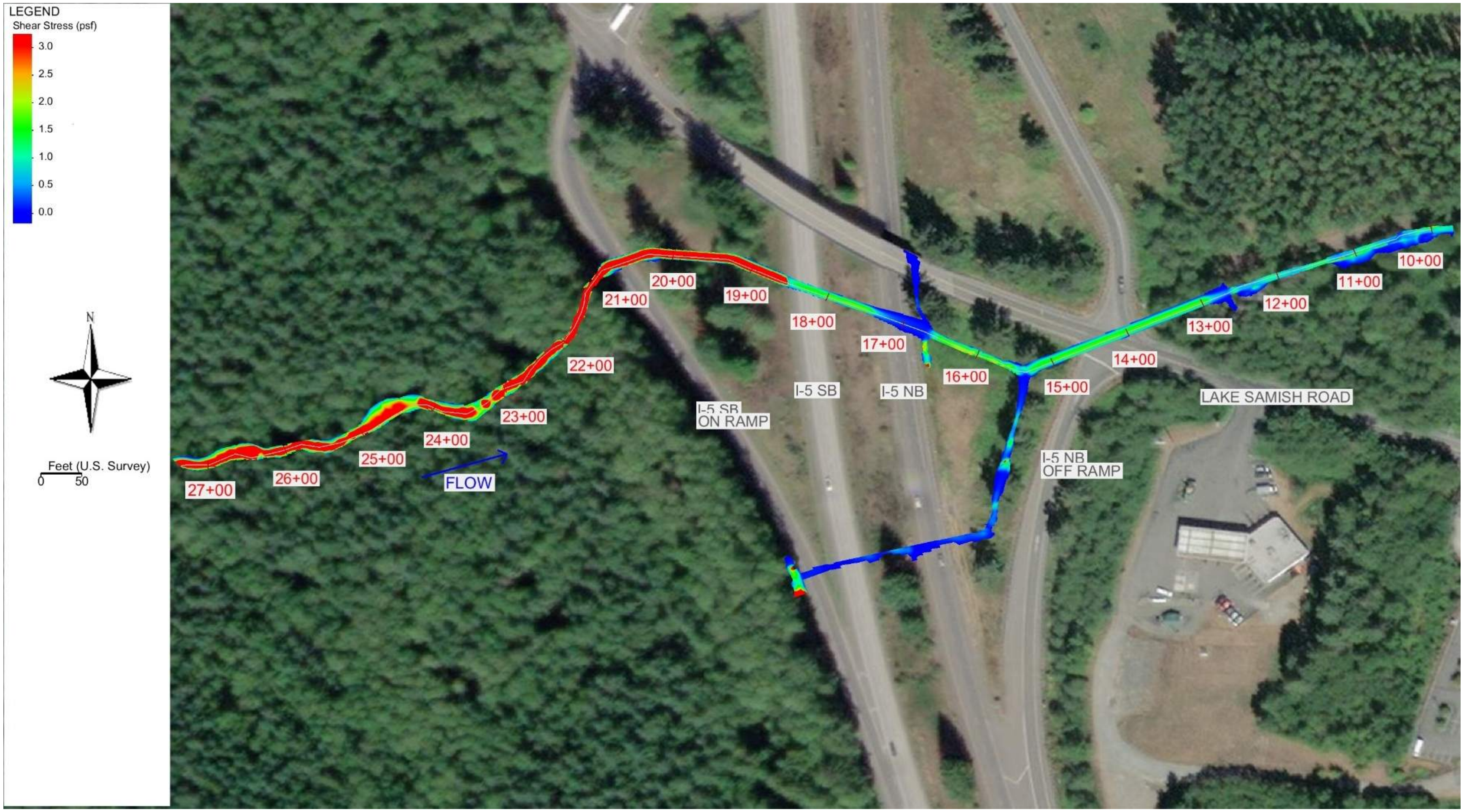
Natural Conditions, 2080 100-Year Flow, Flow Depth (ft)



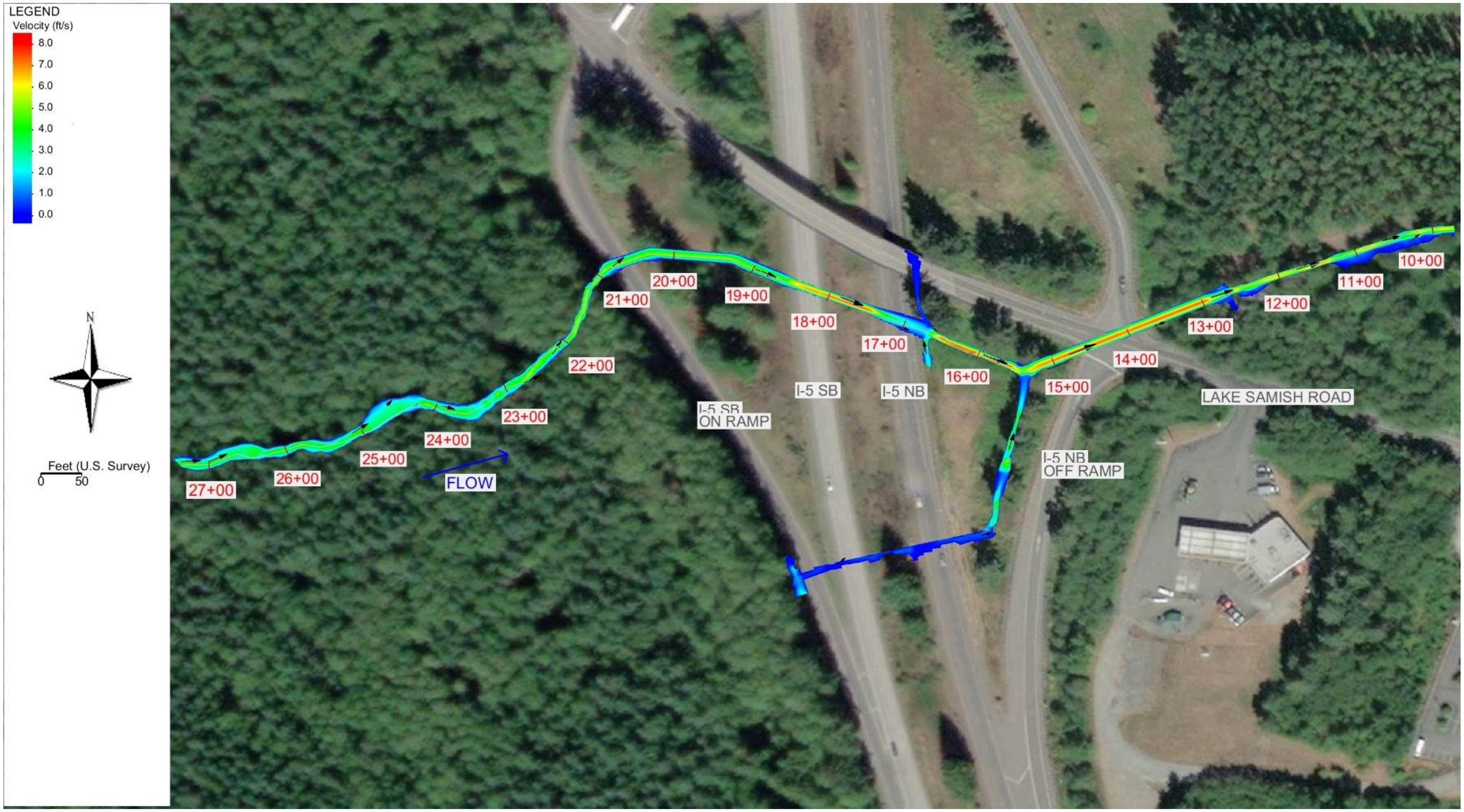
Natural Conditions, 2080 100-Year Flow, Water Surface Elevation (ft)



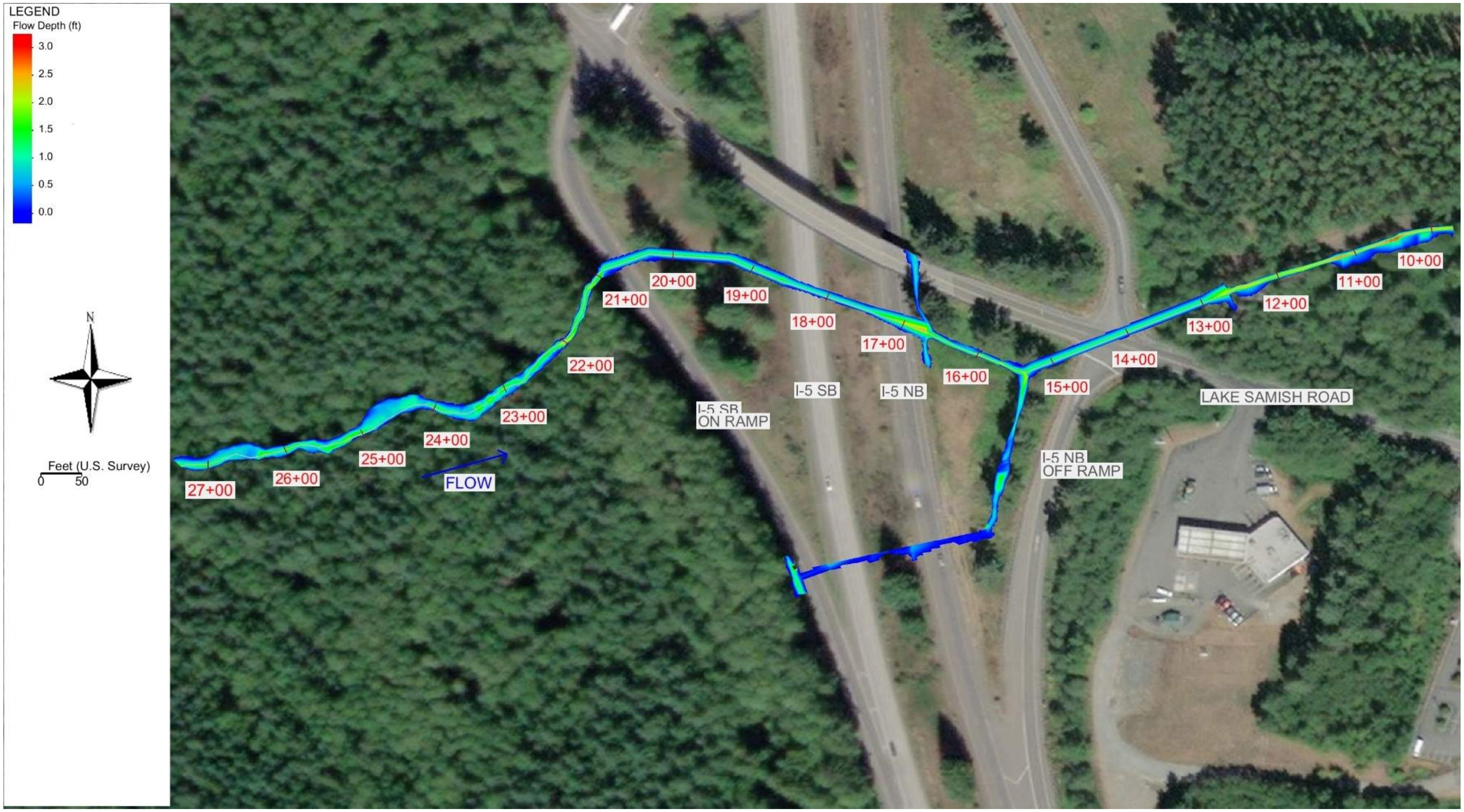
Natural Conditions, 500-Year Flow, Shear Stress (psf)



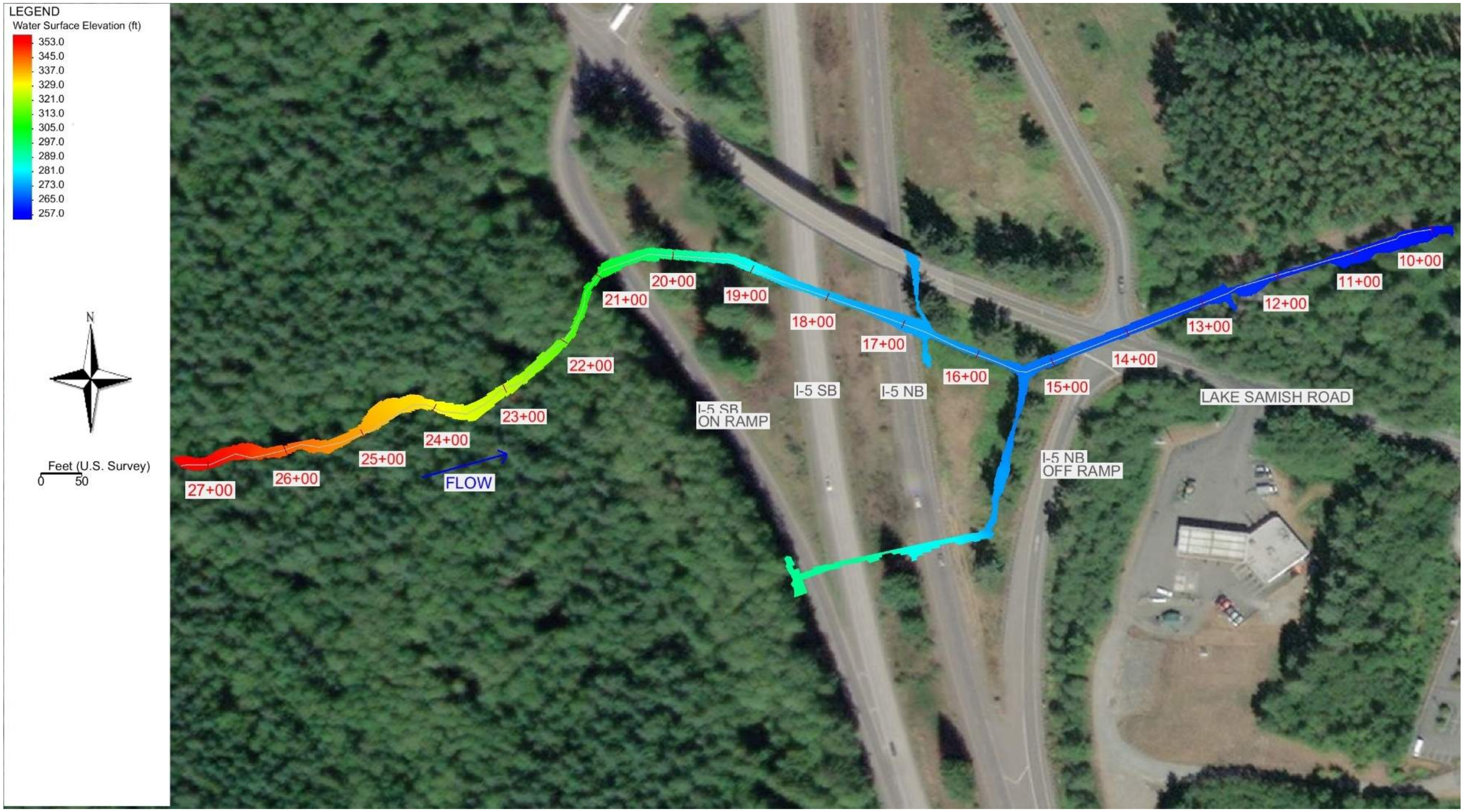
Natural Conditions, 500-Year Flow, Velocity (ft/s)



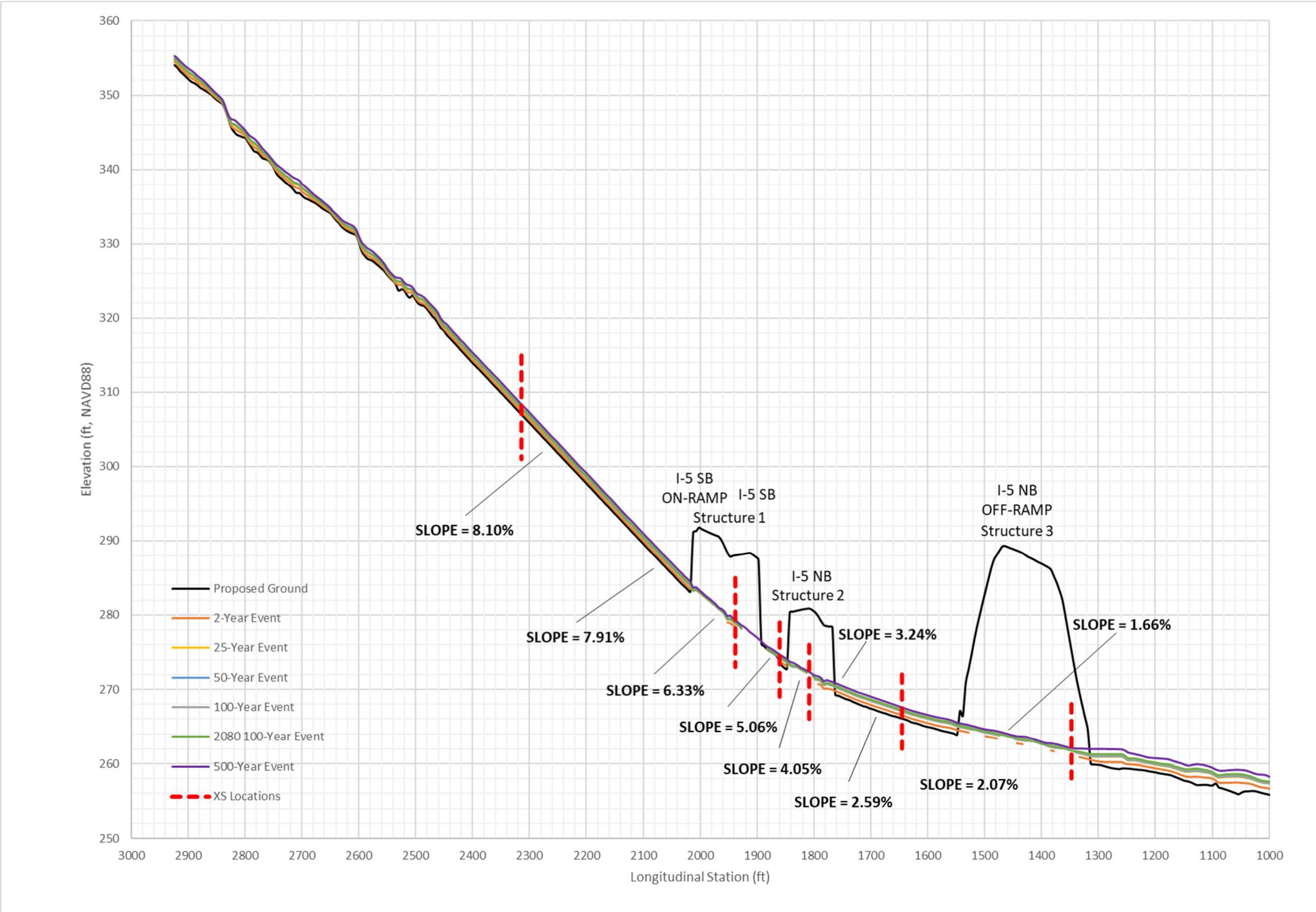
Natural Conditions, 500-Year Flow, Flow Depth (ft)



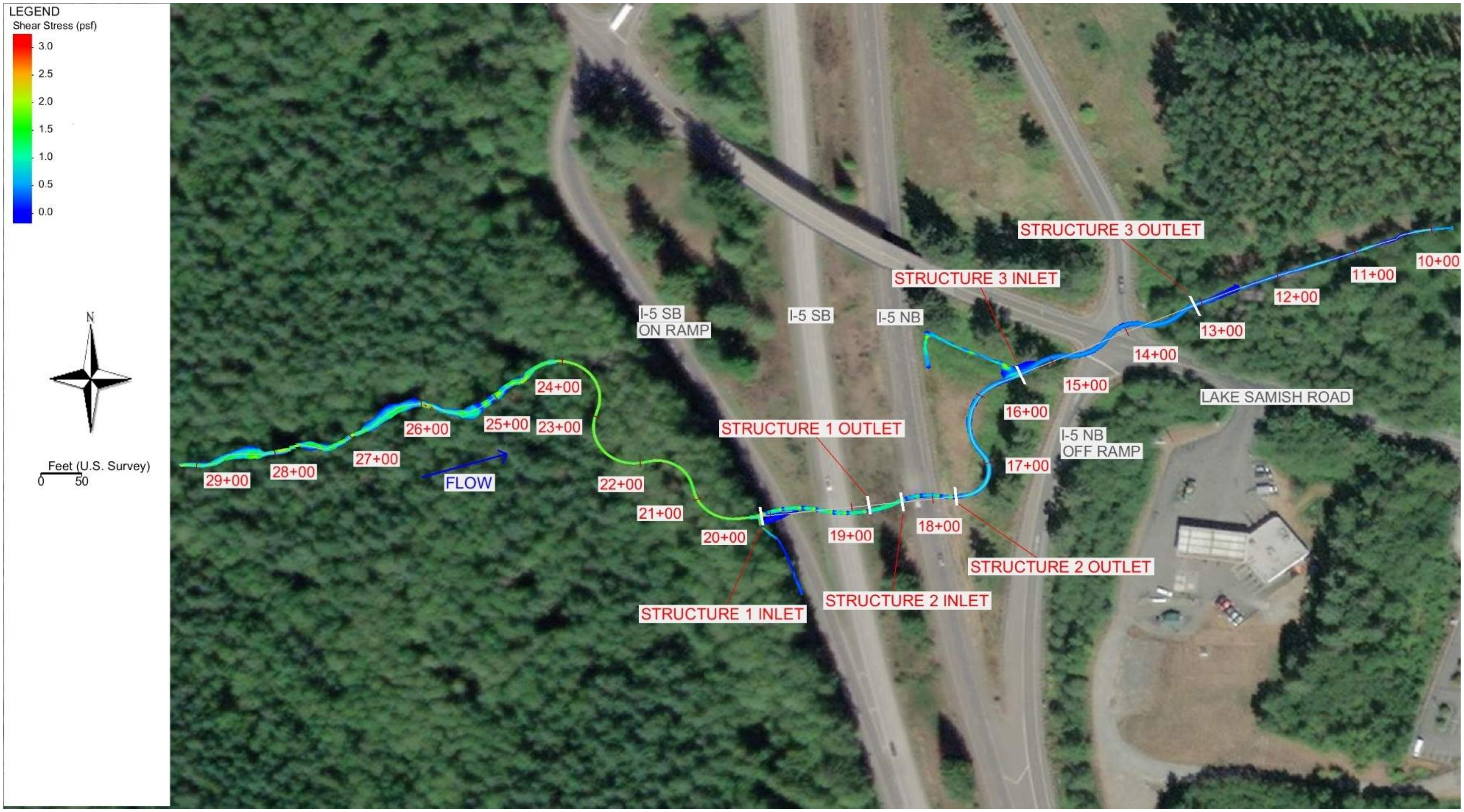
Natural Conditions, 500-Year Flow, Water Surface Elevation (ft)



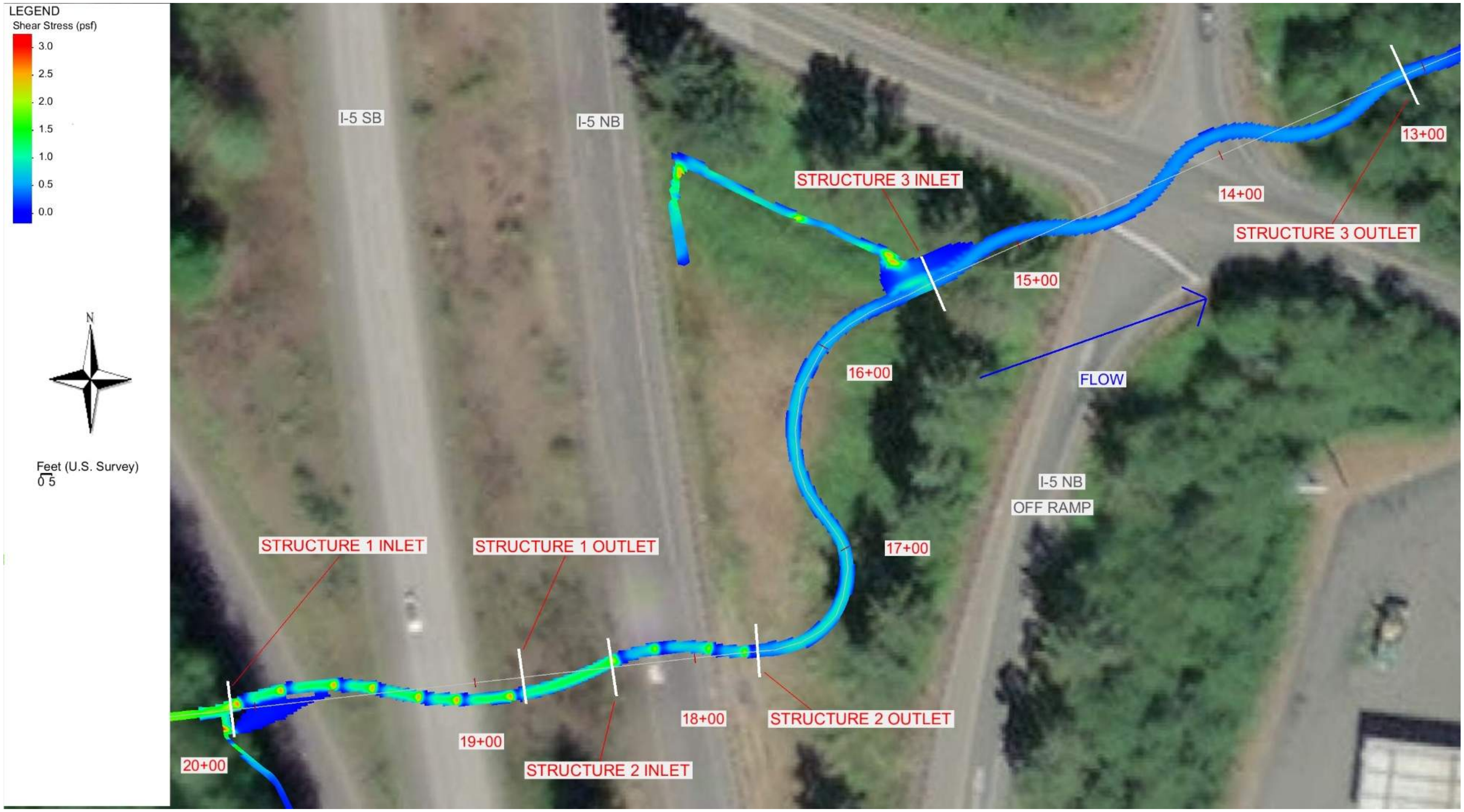
Proposed Conditions Water Surface Profiles



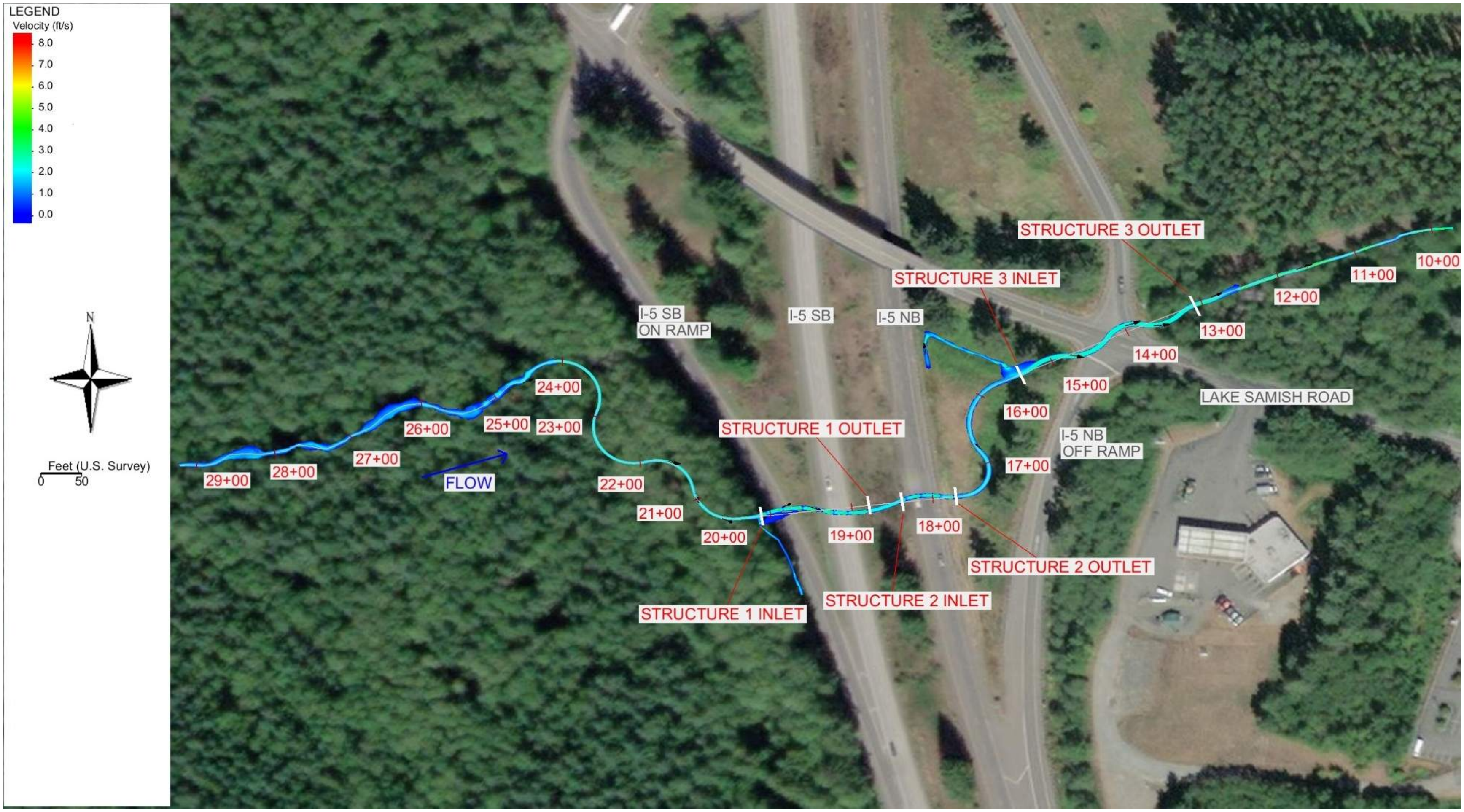
Proposed Conditions, 2-Year Flow, Shear Stress (psf)



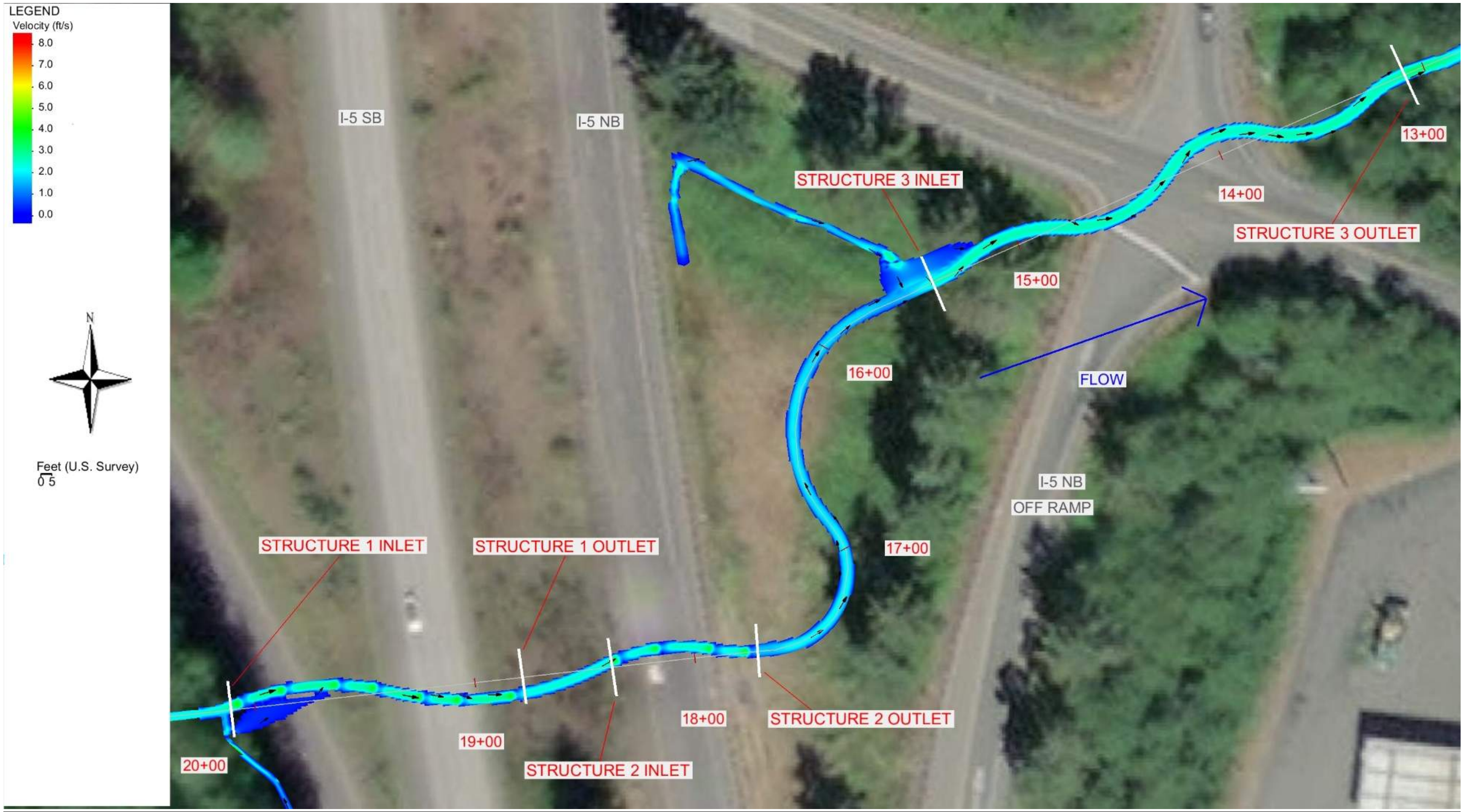
Proposed Conditions, Structure Crossings, 2-Year Flow, Shear Stress (psf)



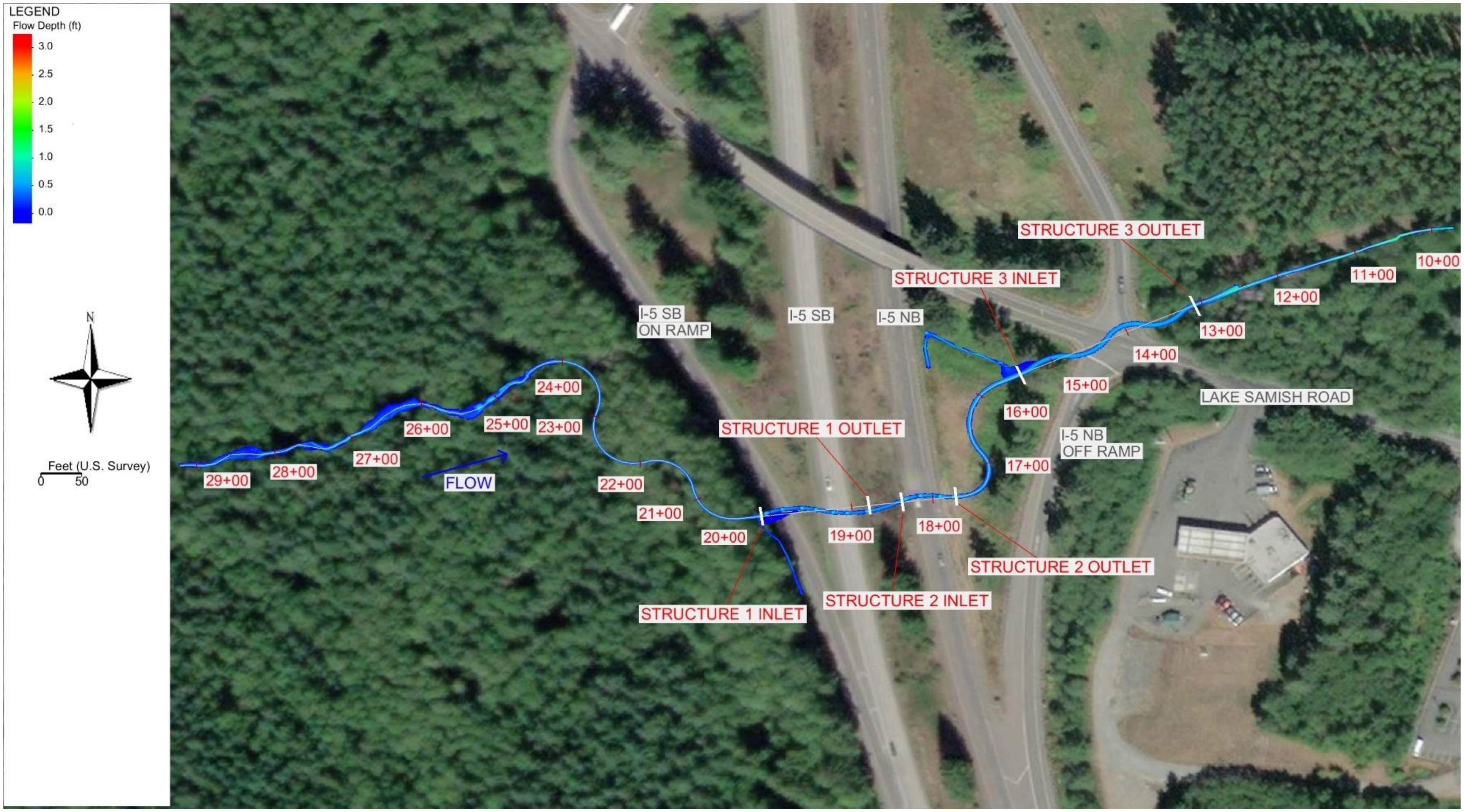
Proposed Conditions, 2-Year Flow, Velocity (ft/s)



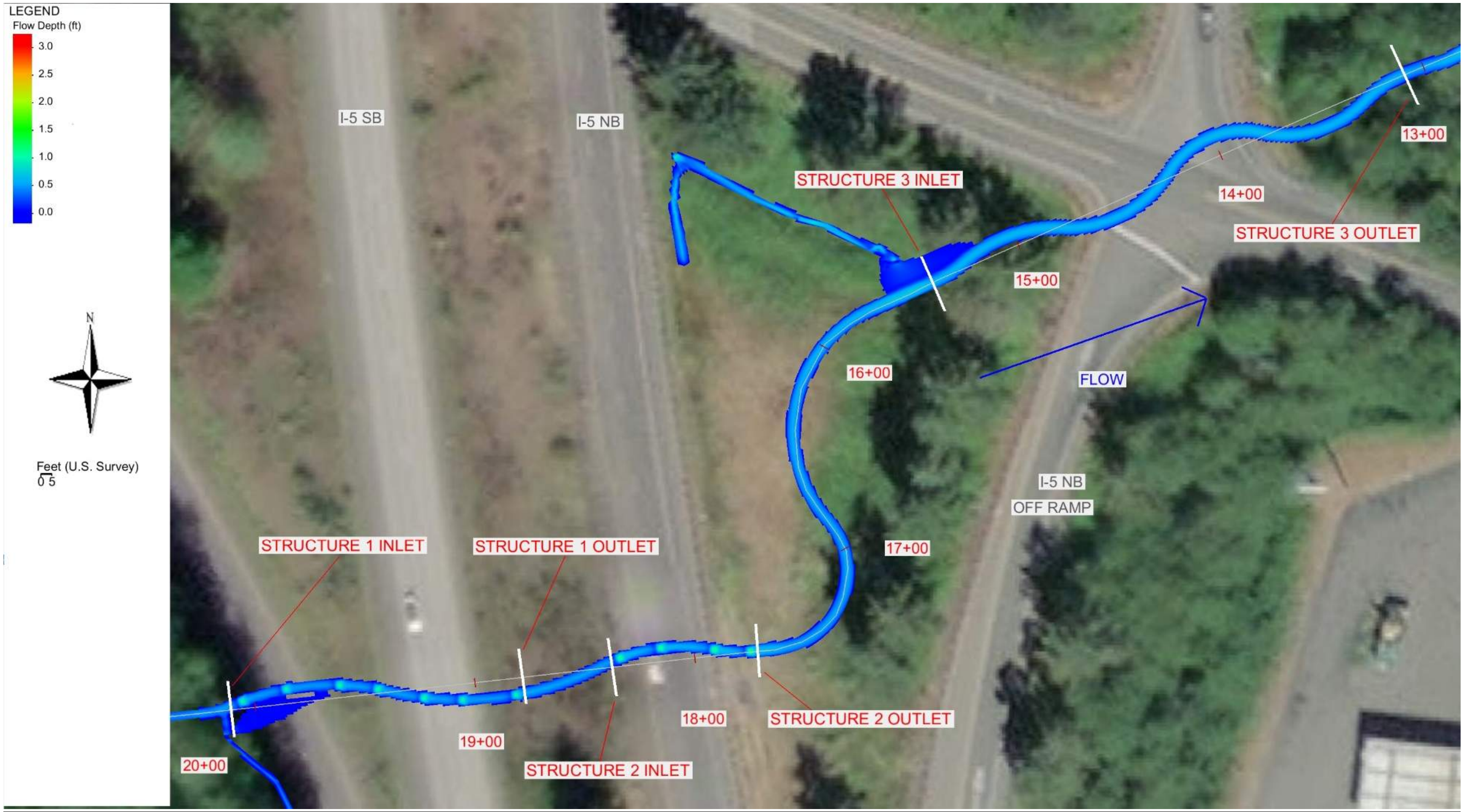
Proposed Conditions, Structure Crossings, 2-Year Flow, Velocity (ft/s)



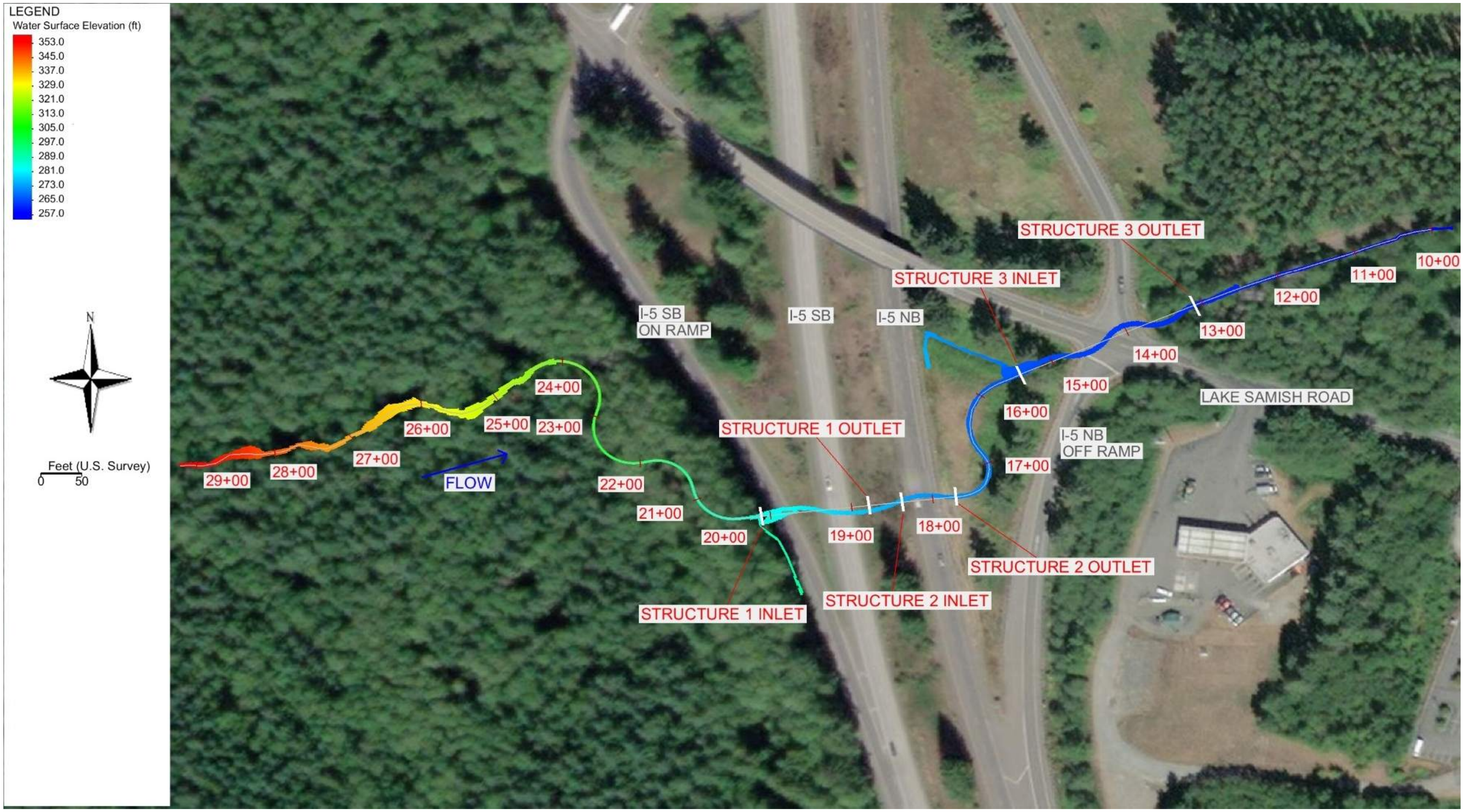
Proposed Conditions, 2-Year Flow, Flow Depth (ft)



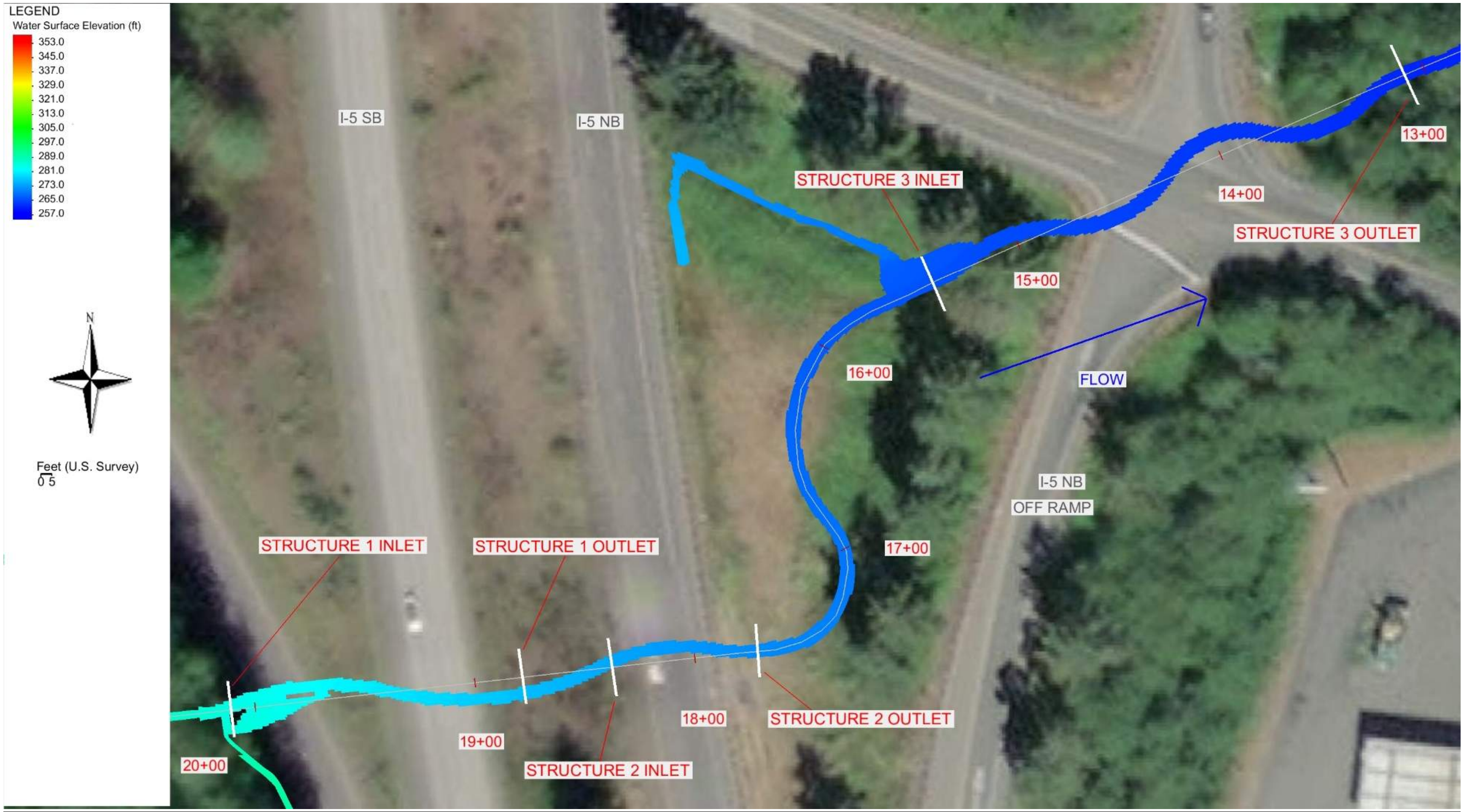
Proposed Conditions, Structure Crossings, 2-Year Flow, Flow Depth (ft)



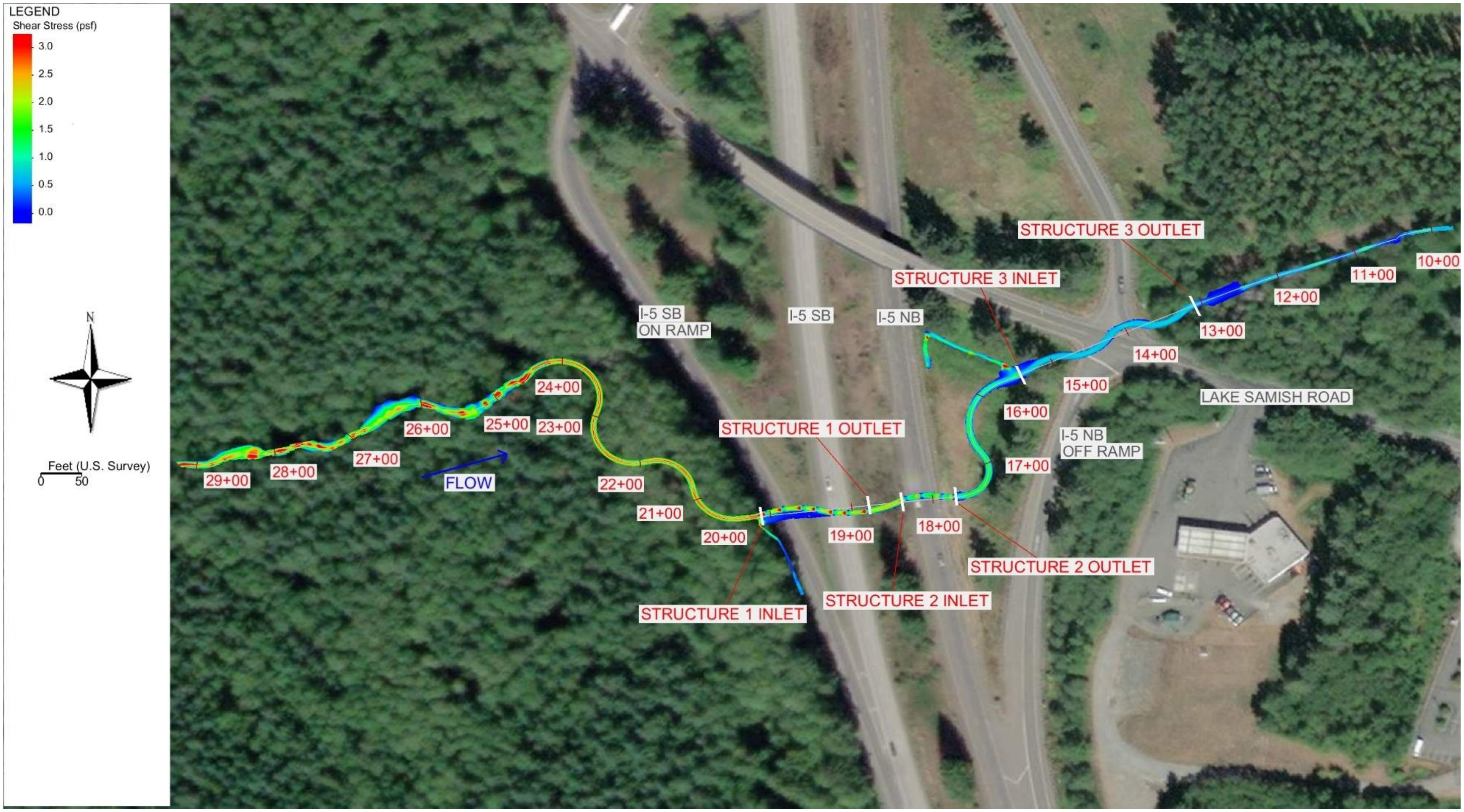
Proposed Conditions, 2-Year Flow, Water Surface Elevation (ft)



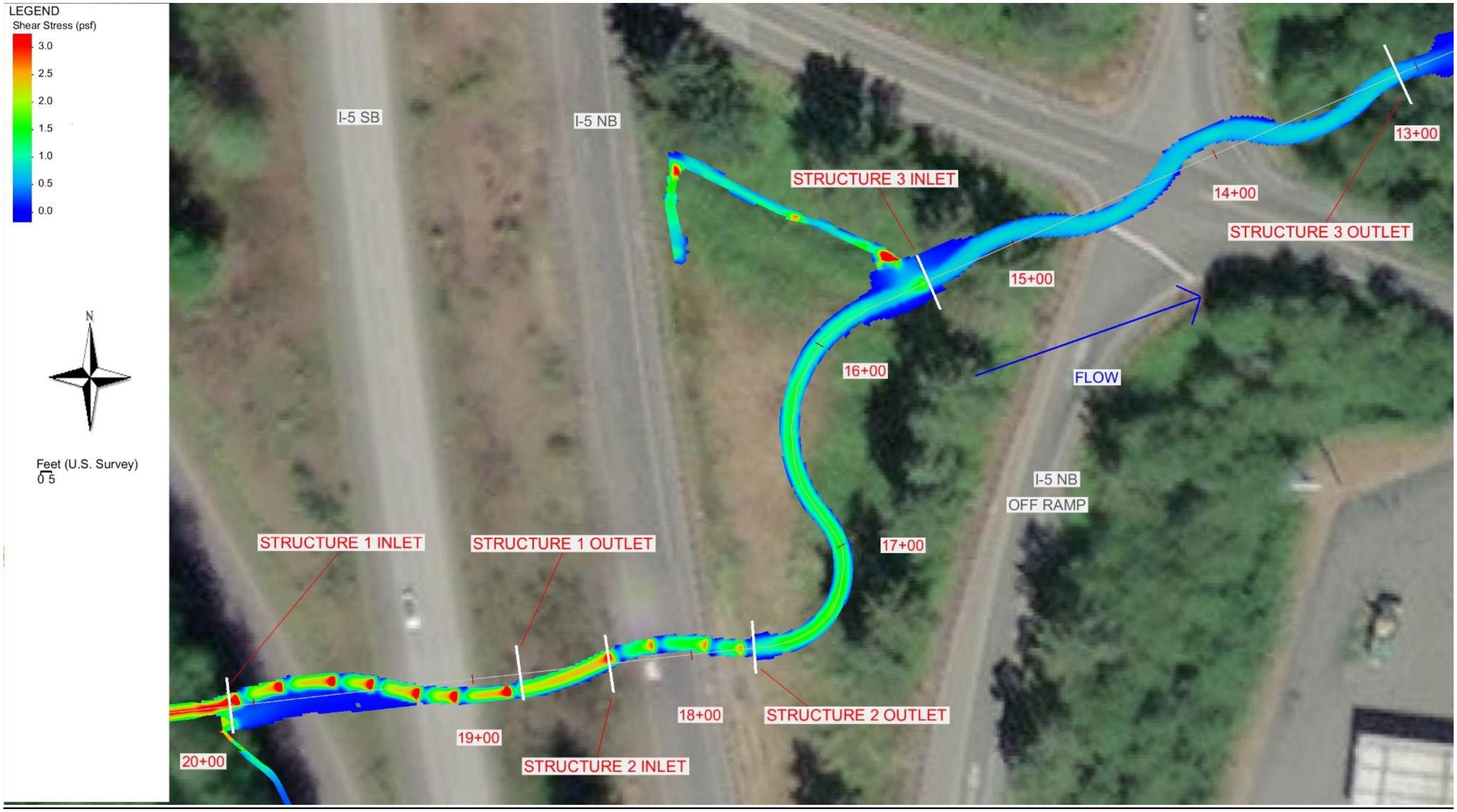
Proposed Conditions, Structure Crossings, 2-Year Flow, Water Surface Elevation (ft)



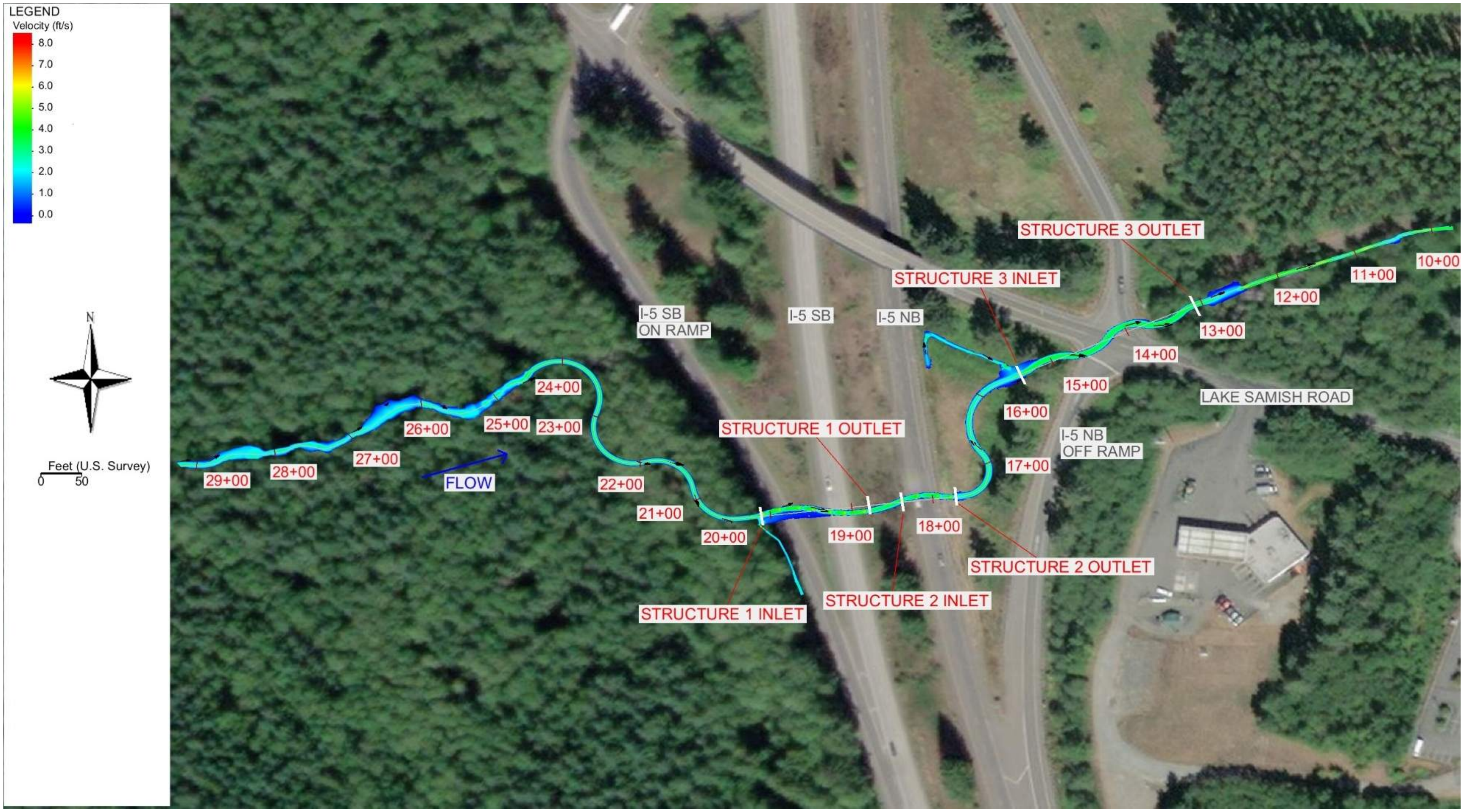
Proposed Conditions, 25-Year Flow, Shear Stress (psf)



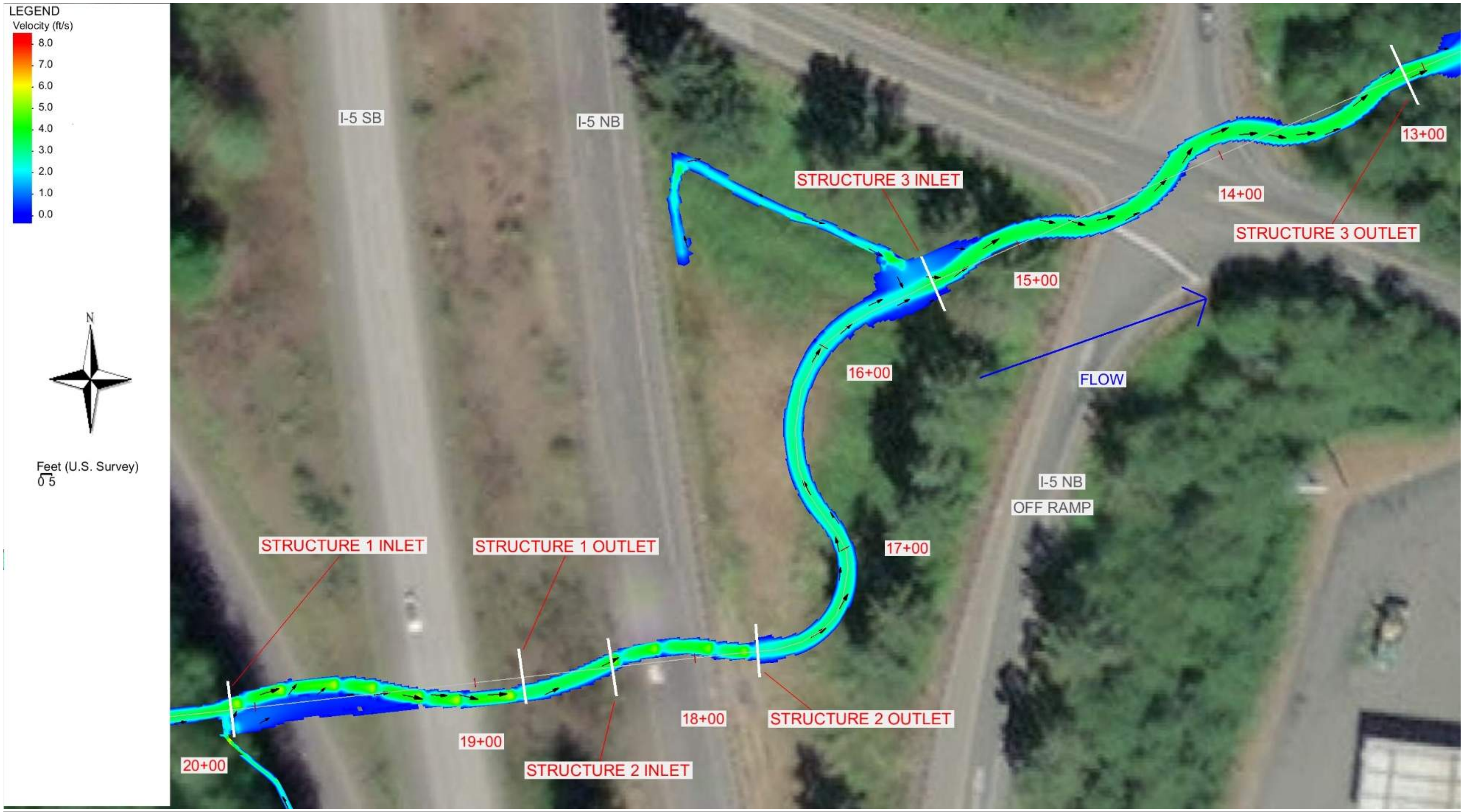
Proposed Conditions, Structure Crossings, 25-Year Flow, Shear Stress (psf)



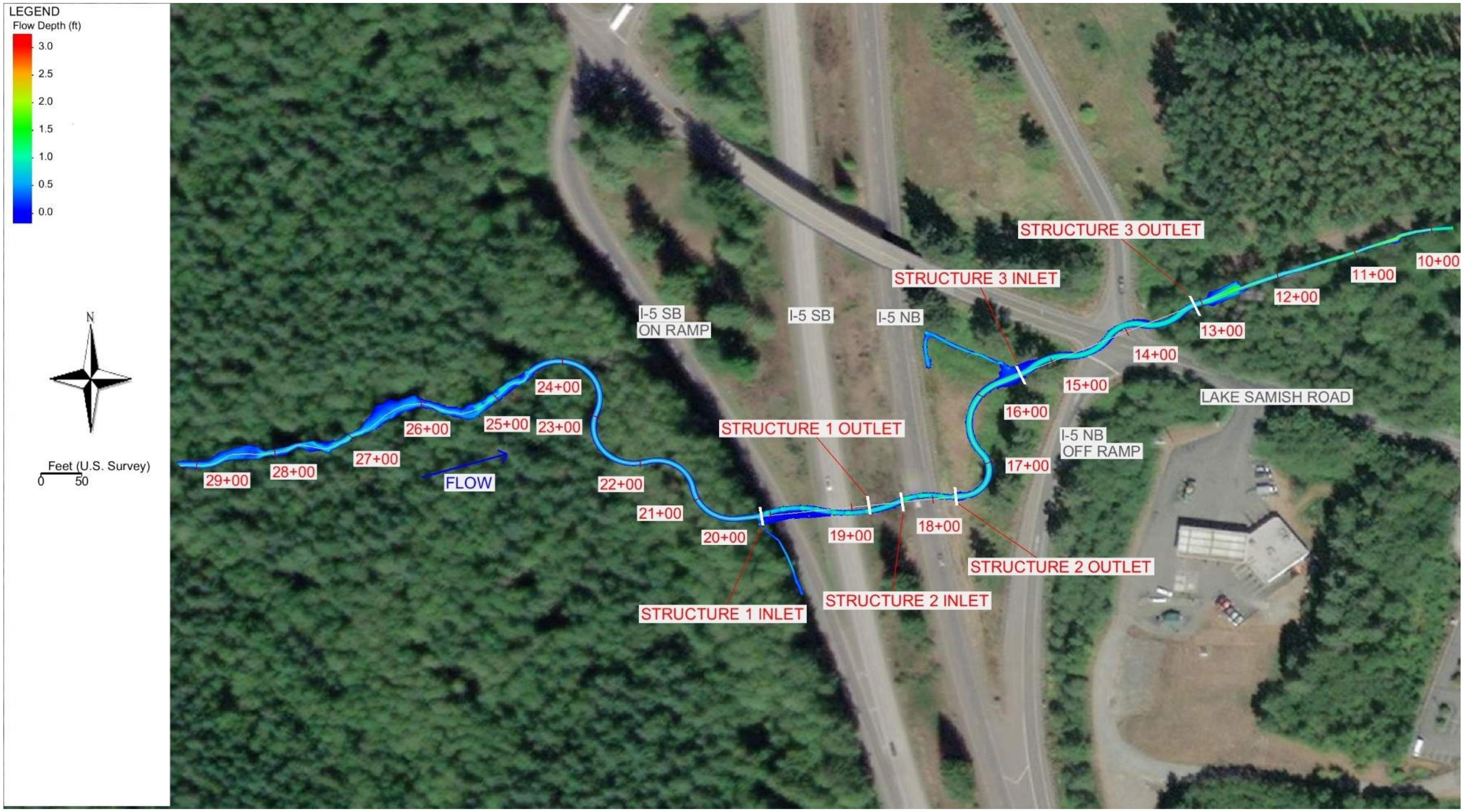
Proposed Conditions, 25-Year Flow, Velocity (ft/s)



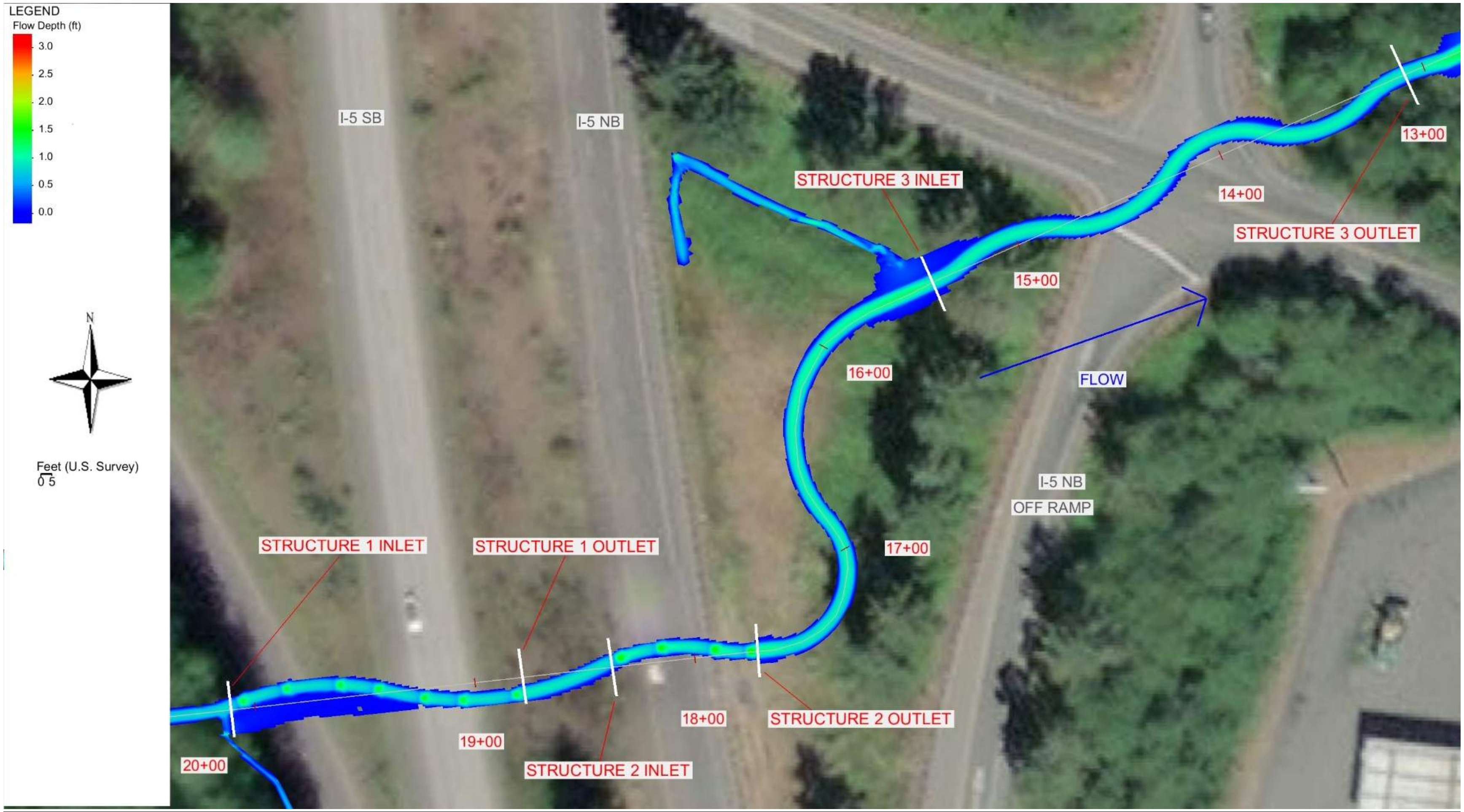
Proposed Conditions, Structure Crossings, 25-Year Flow, Velocity (ft/s)



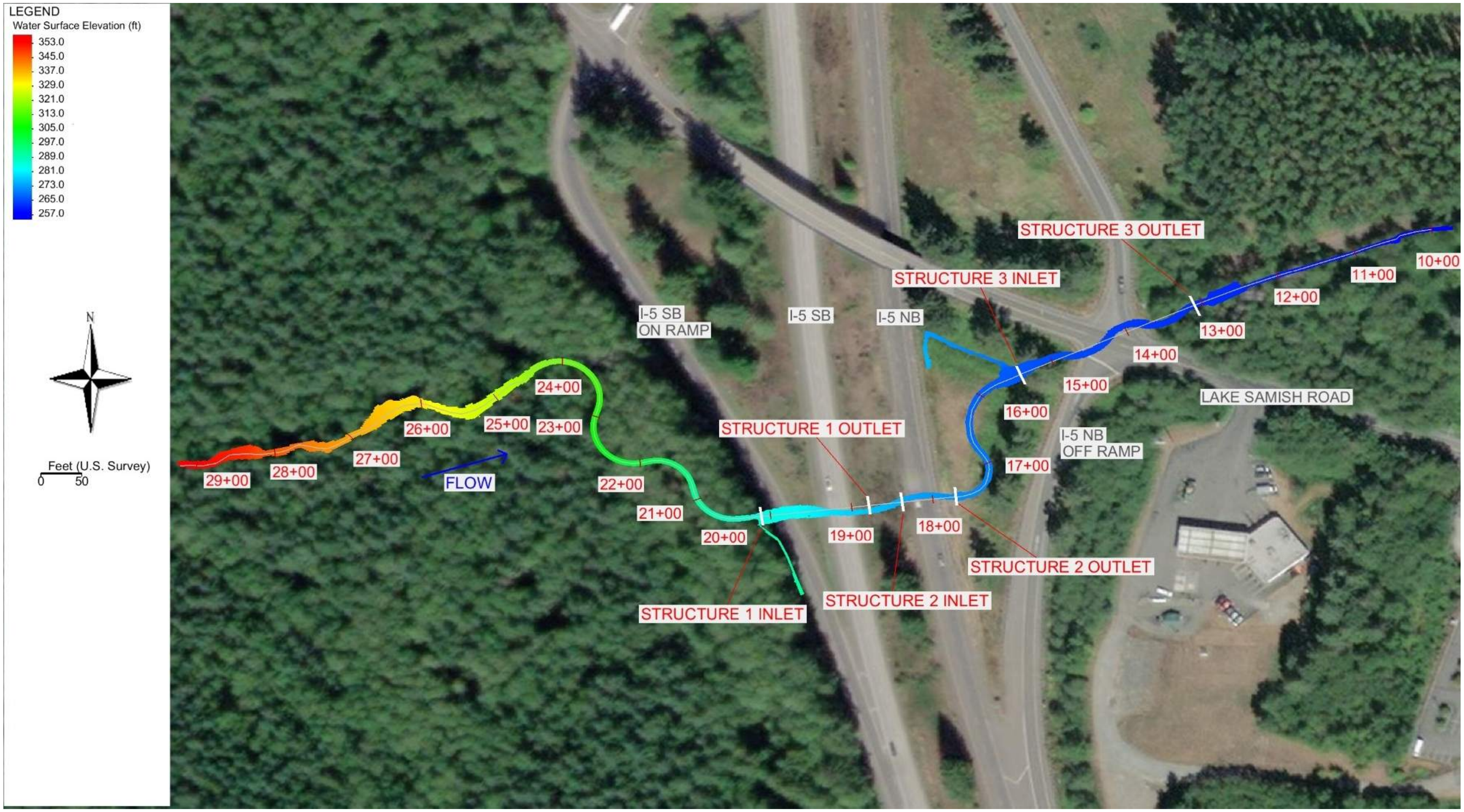
Proposed Conditions, 25-Year Flow, Flow Depth (ft)



Proposed Conditions, Structure Crossings, 25-Year Flow, Flow Depth (ft)

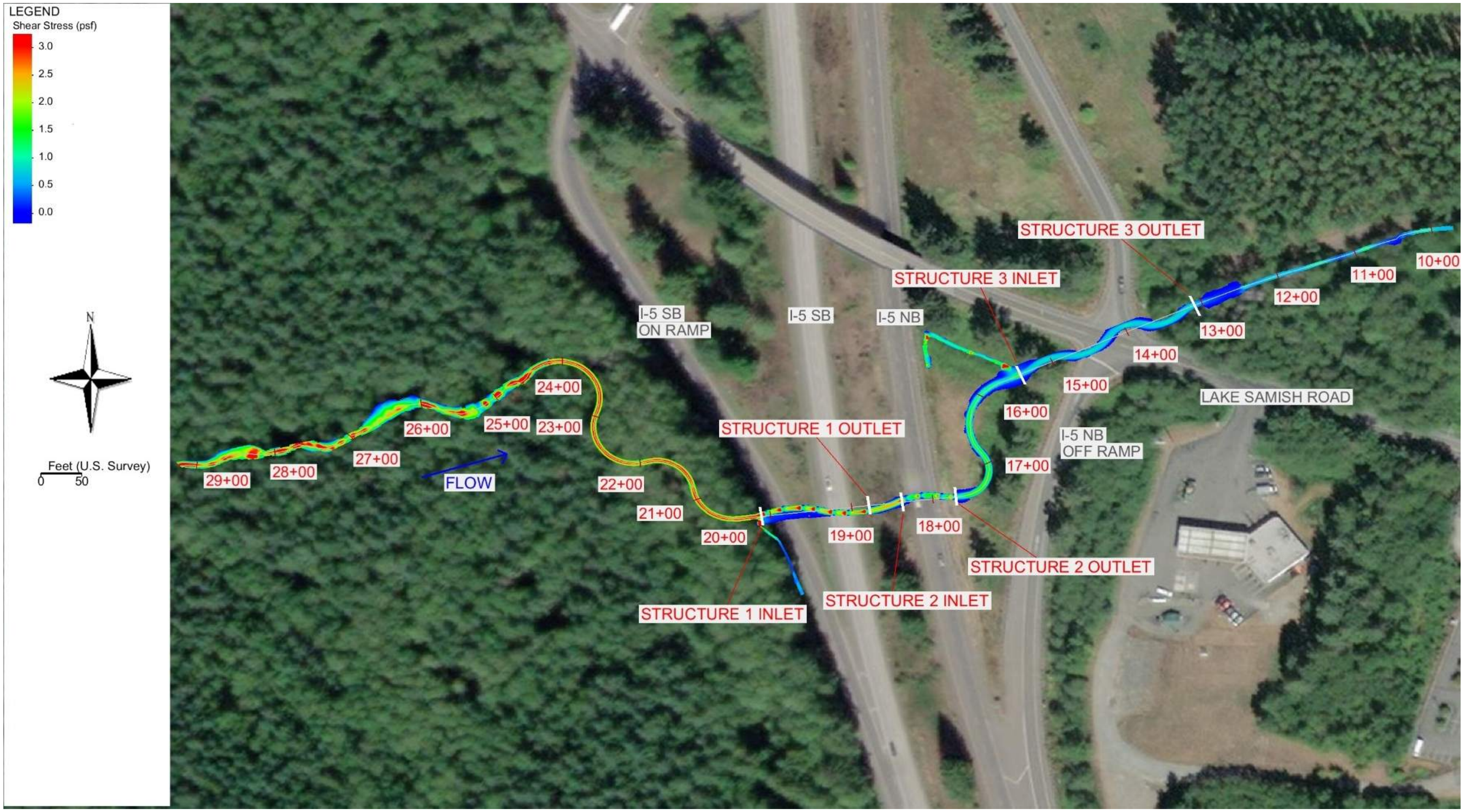


Proposed Conditions, 25-Year Flow, Water Surface Elevation (ft)

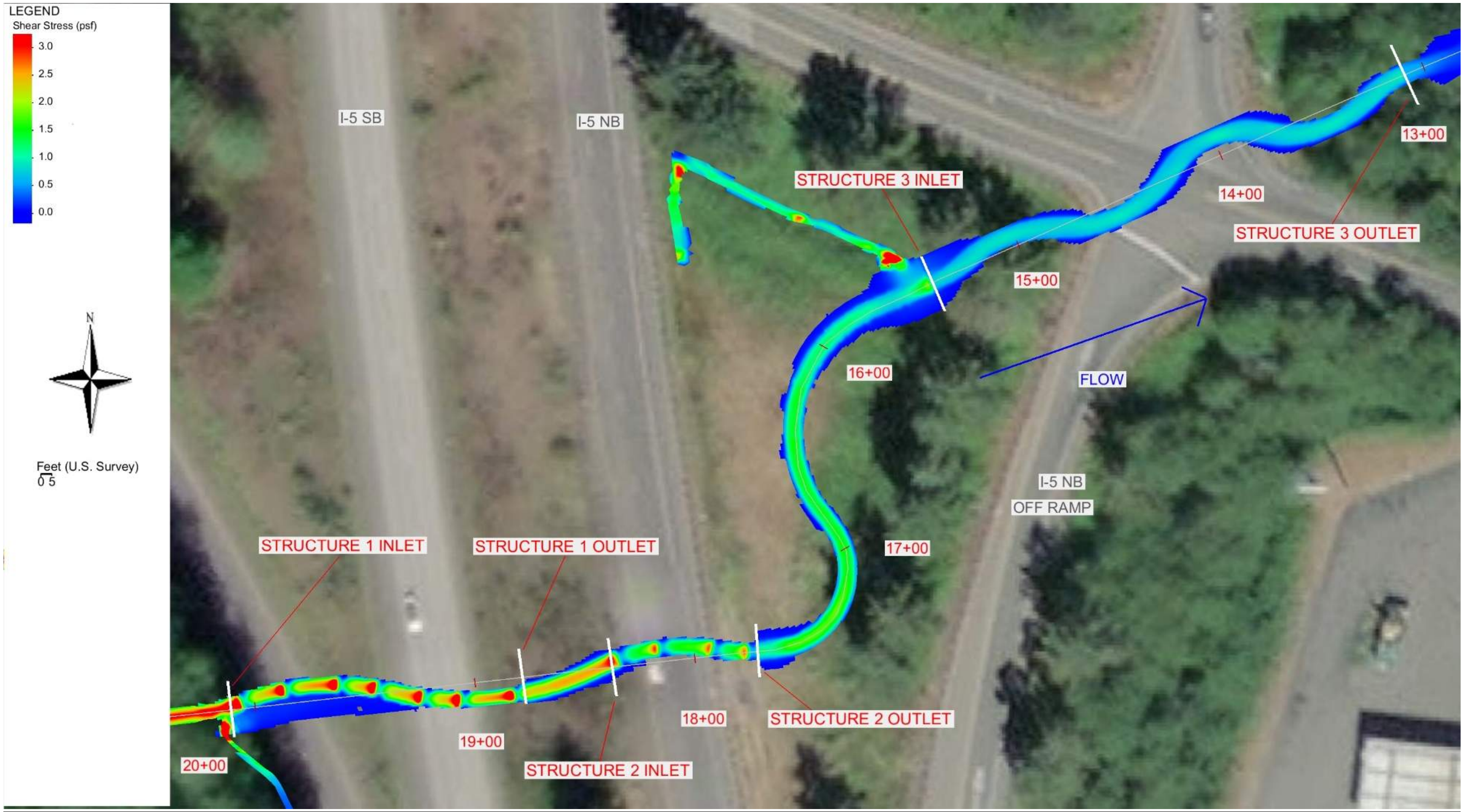


Proposed Conditions, Structure Crossings, 25-Year Flow, Water Surface Elevation (ft)

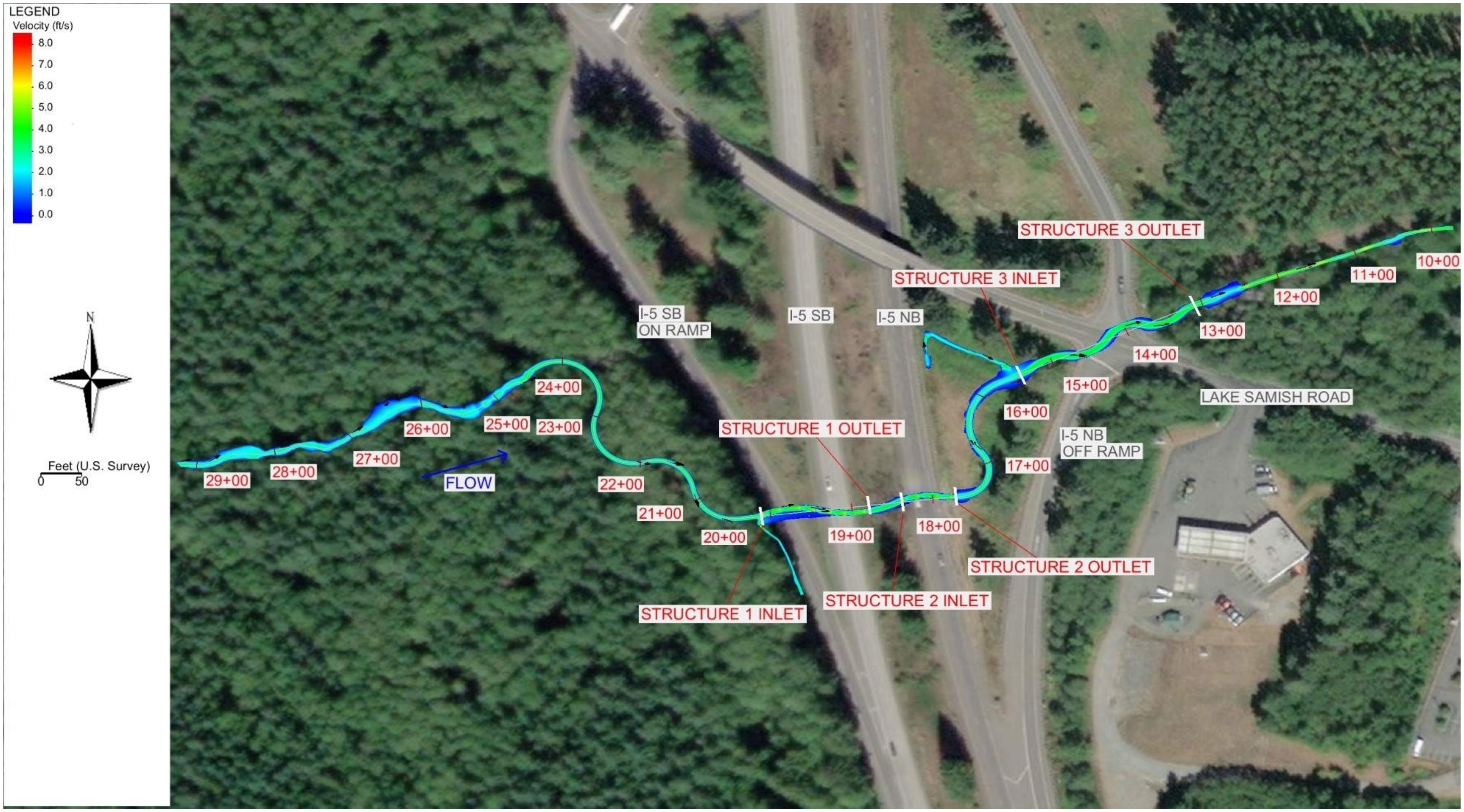
Proposed Conditions, 50-Year Flow, Shear Stress (psf)



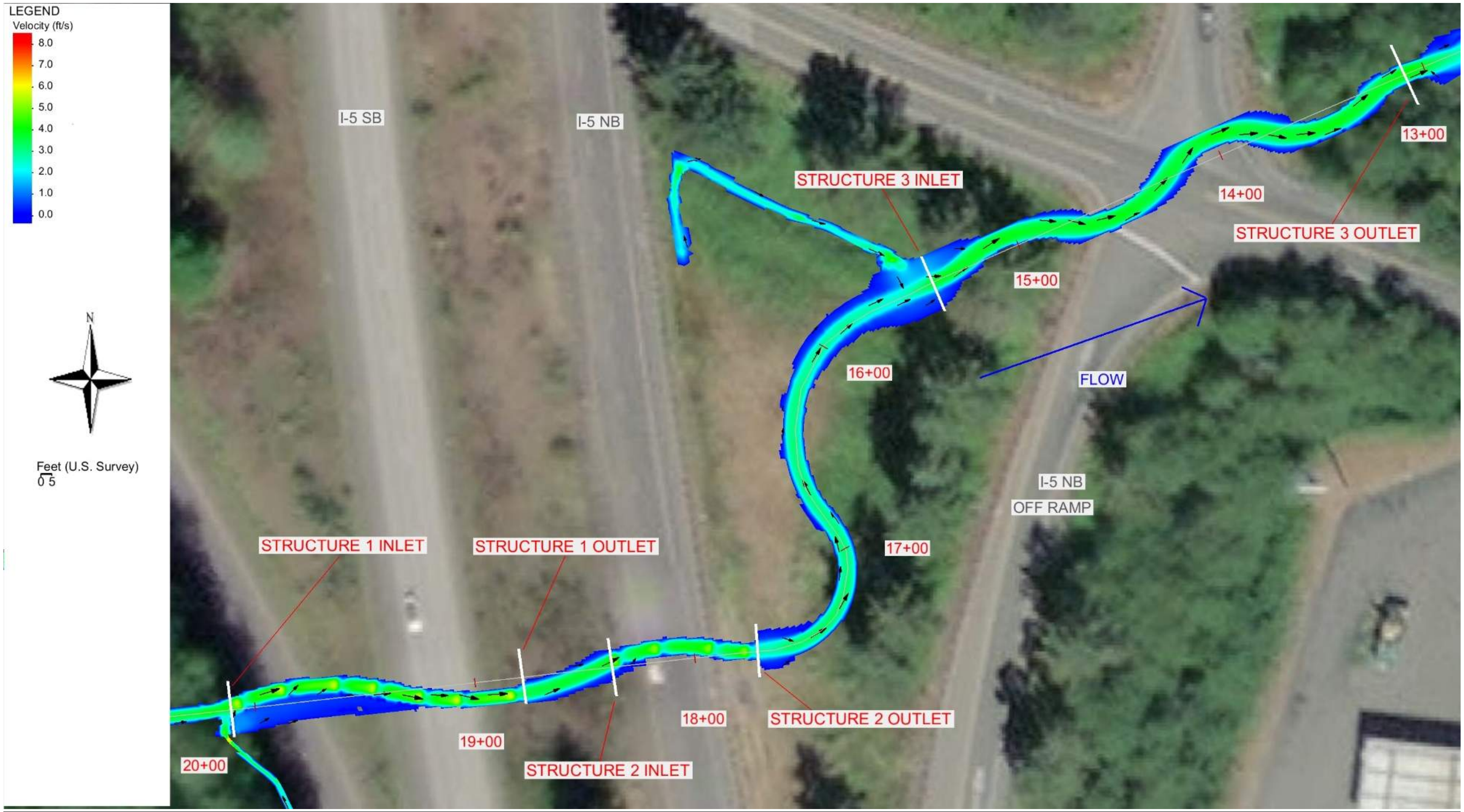
Proposed Conditions, Structure Crossings, 50-Year Flow, Shear Stress (psf)



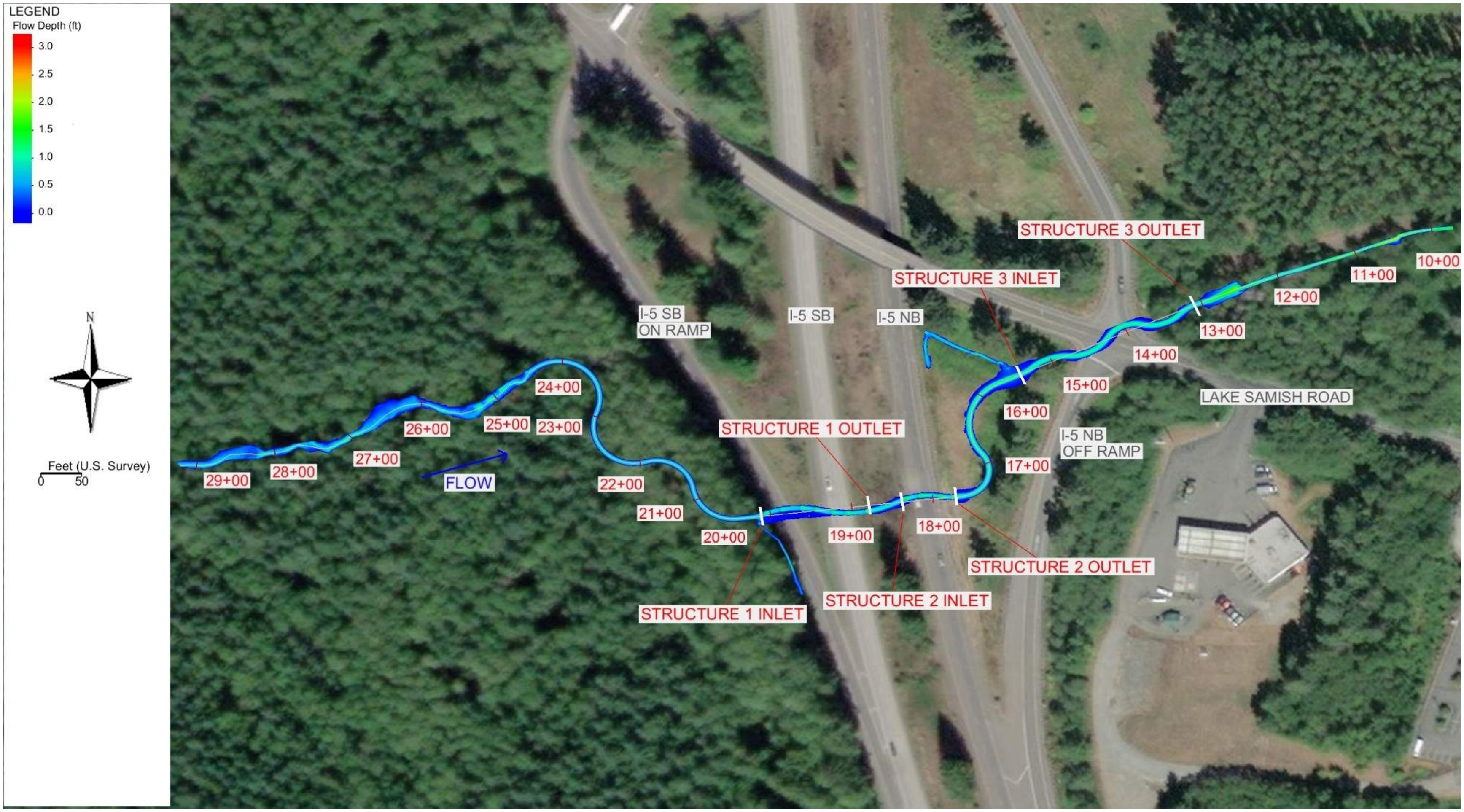
Proposed Conditions, 50-Year Flow, Velocity (ft/s)



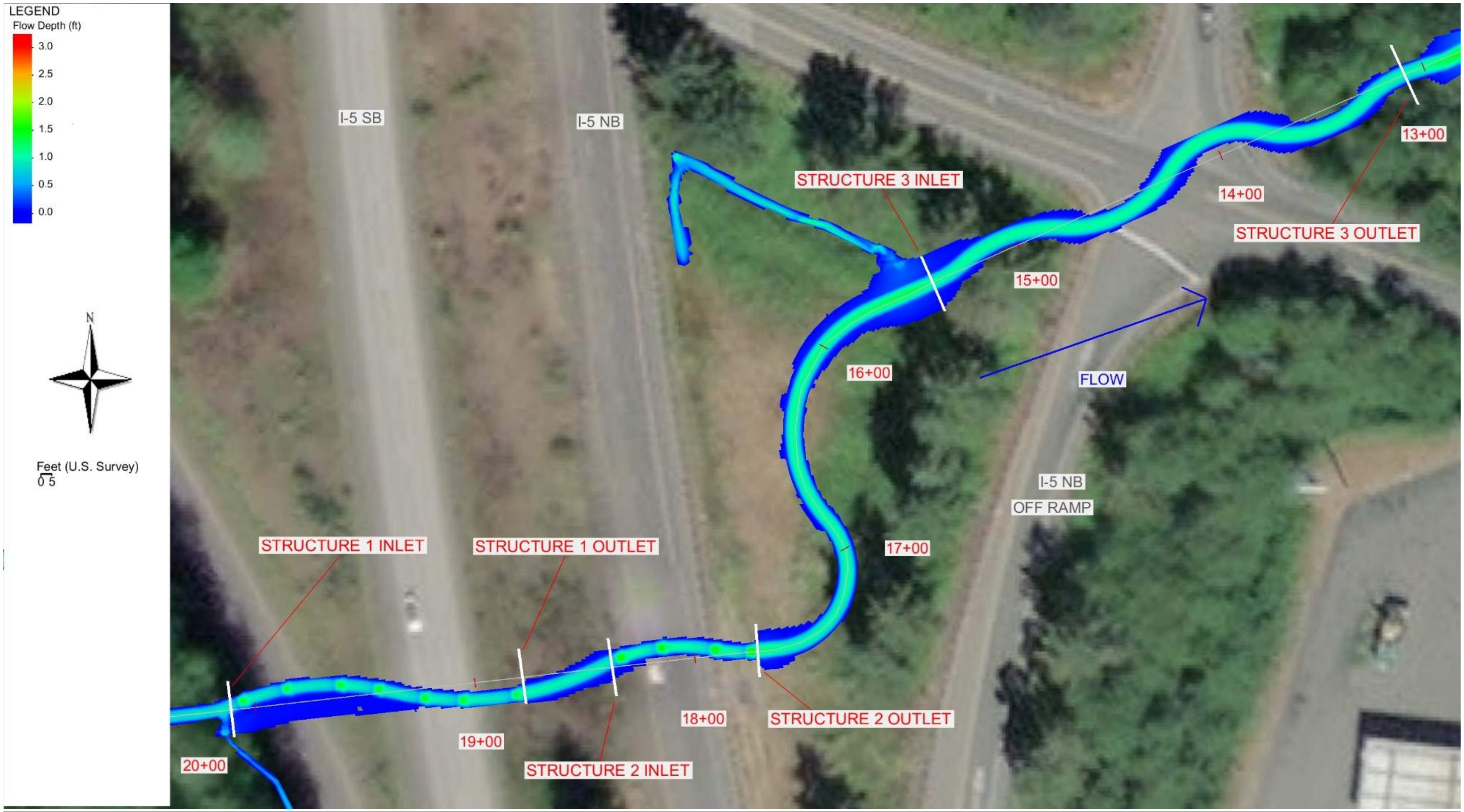
Proposed Conditions, Structure Crossings, 50-Year Flow, Velocity (ft/s)



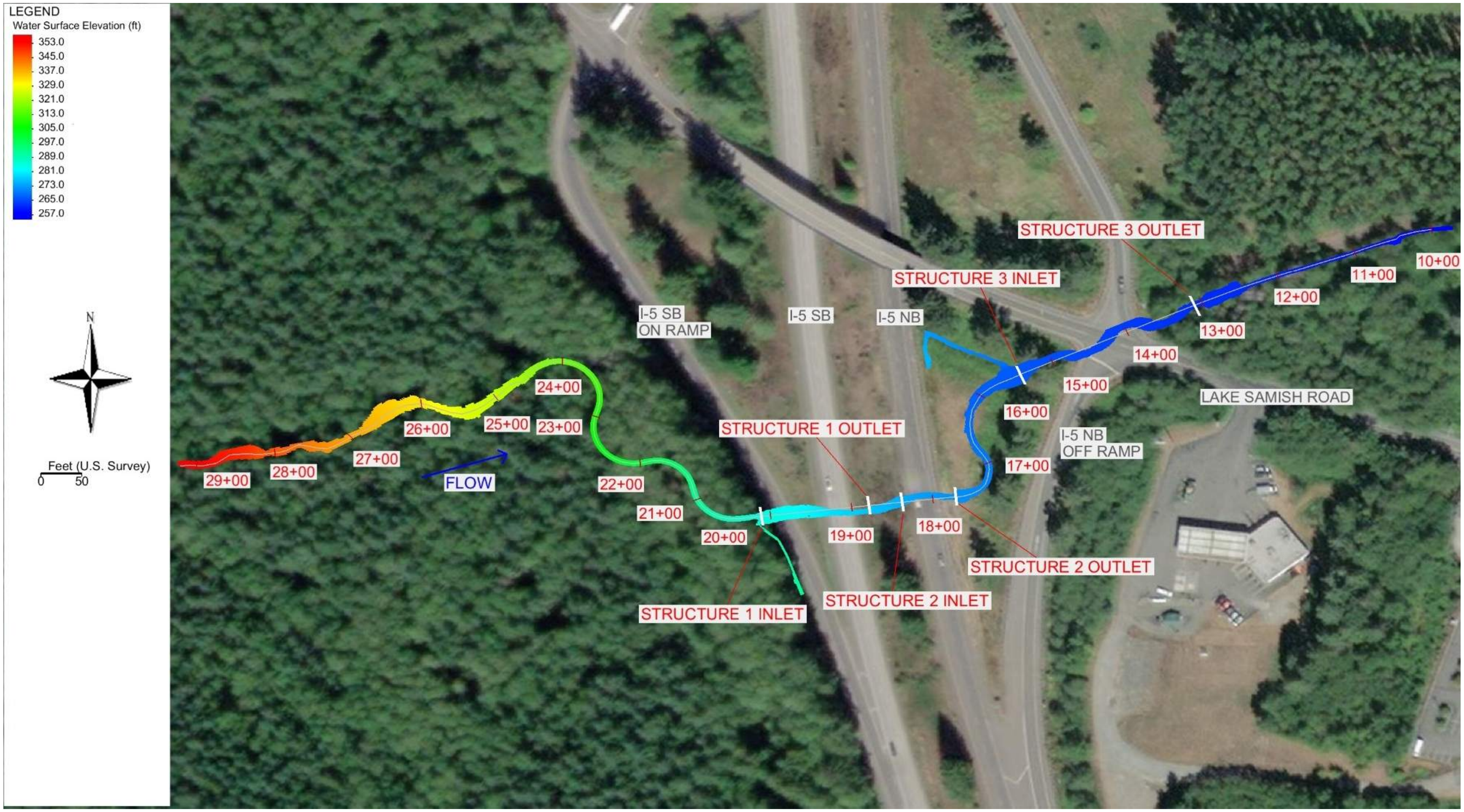
Proposed Conditions, 50-Year Flow, Flow Depth (ft)



Proposed Conditions, Structure Crossings, 50-Year Flow, Flow Depth (ft)

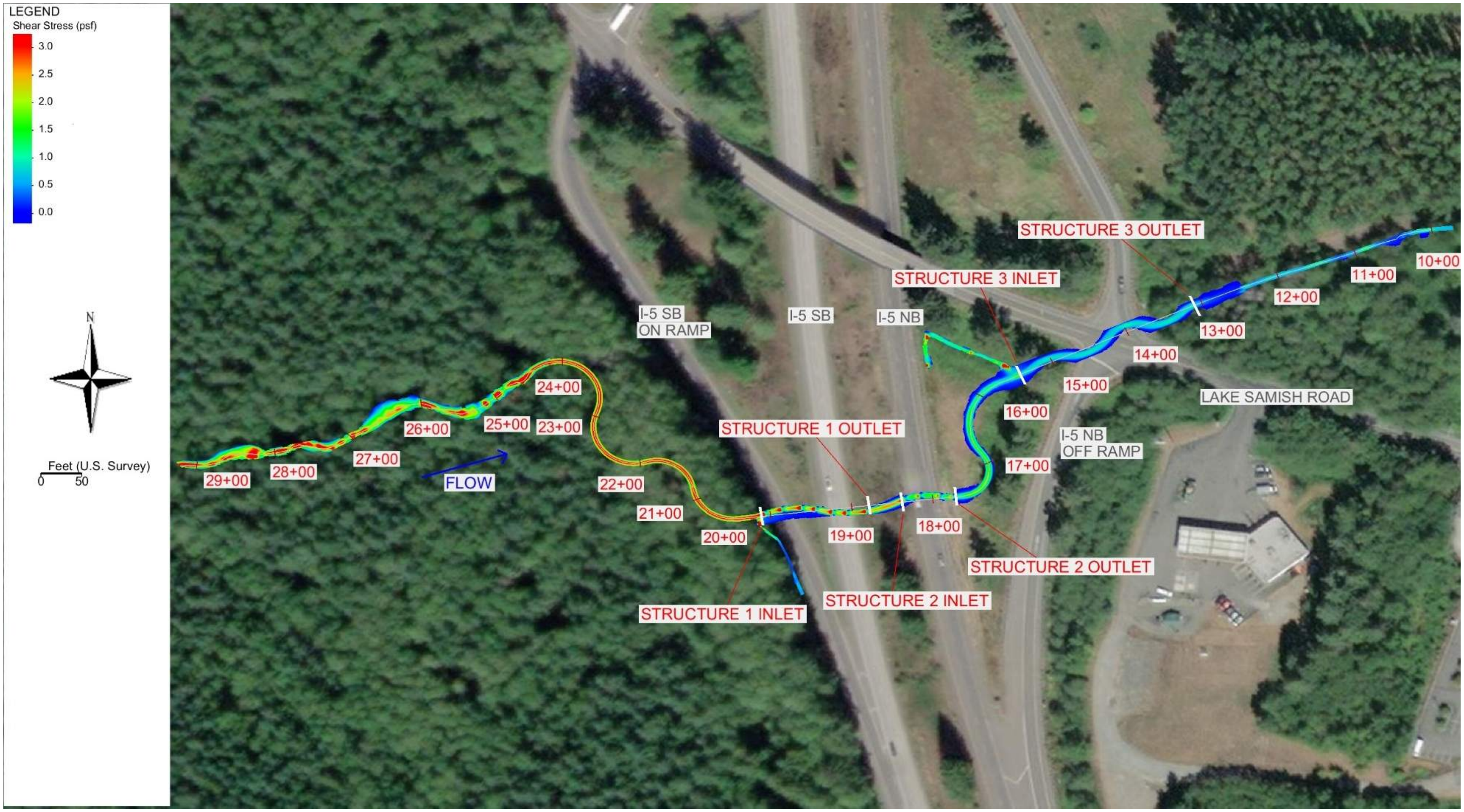


Proposed Conditions, 50-Year Flow, Water Surface Elevation (ft)

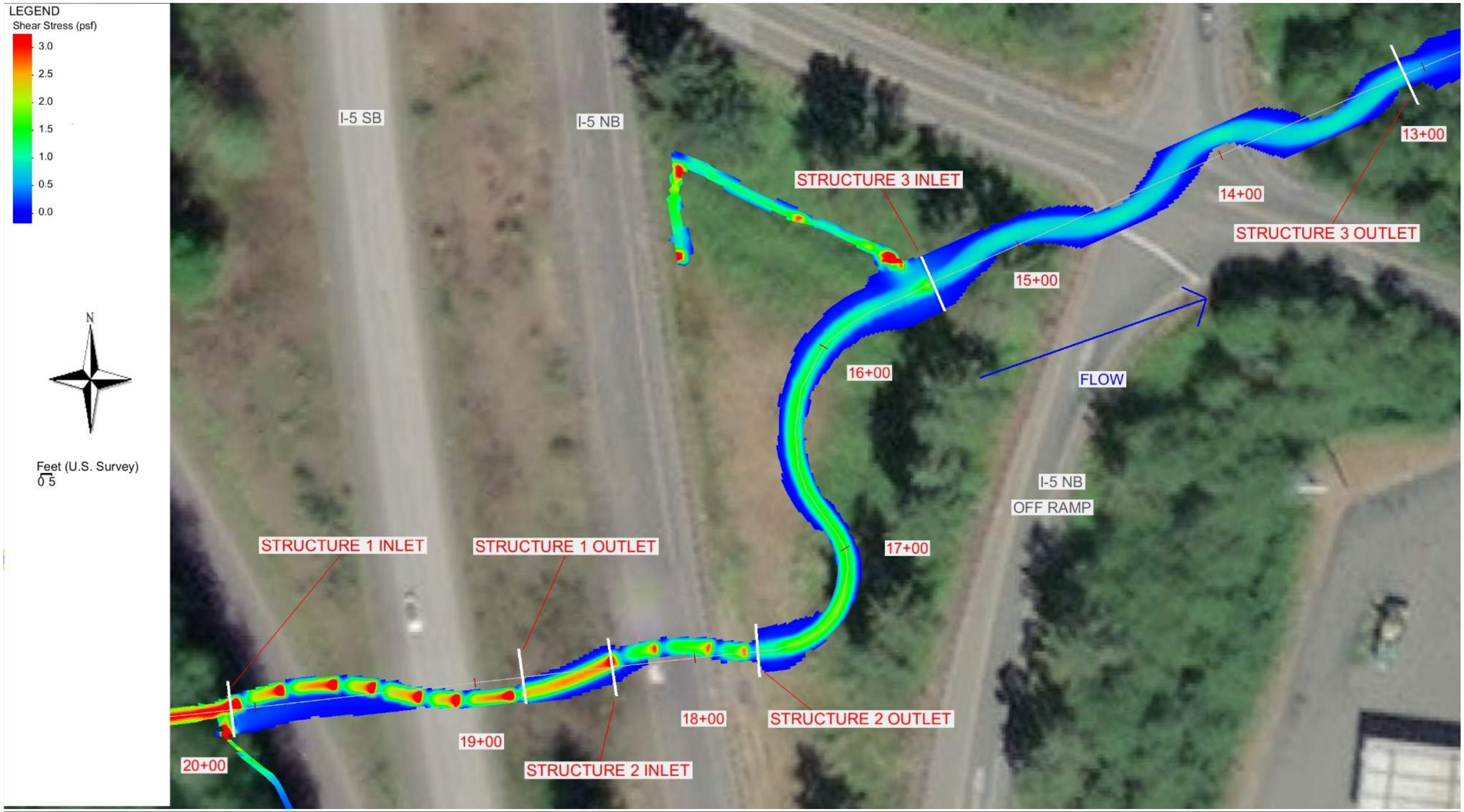


Proposed Conditions, Structure Crossings, 50-Year Flow, Water Surface Elevation (ft)

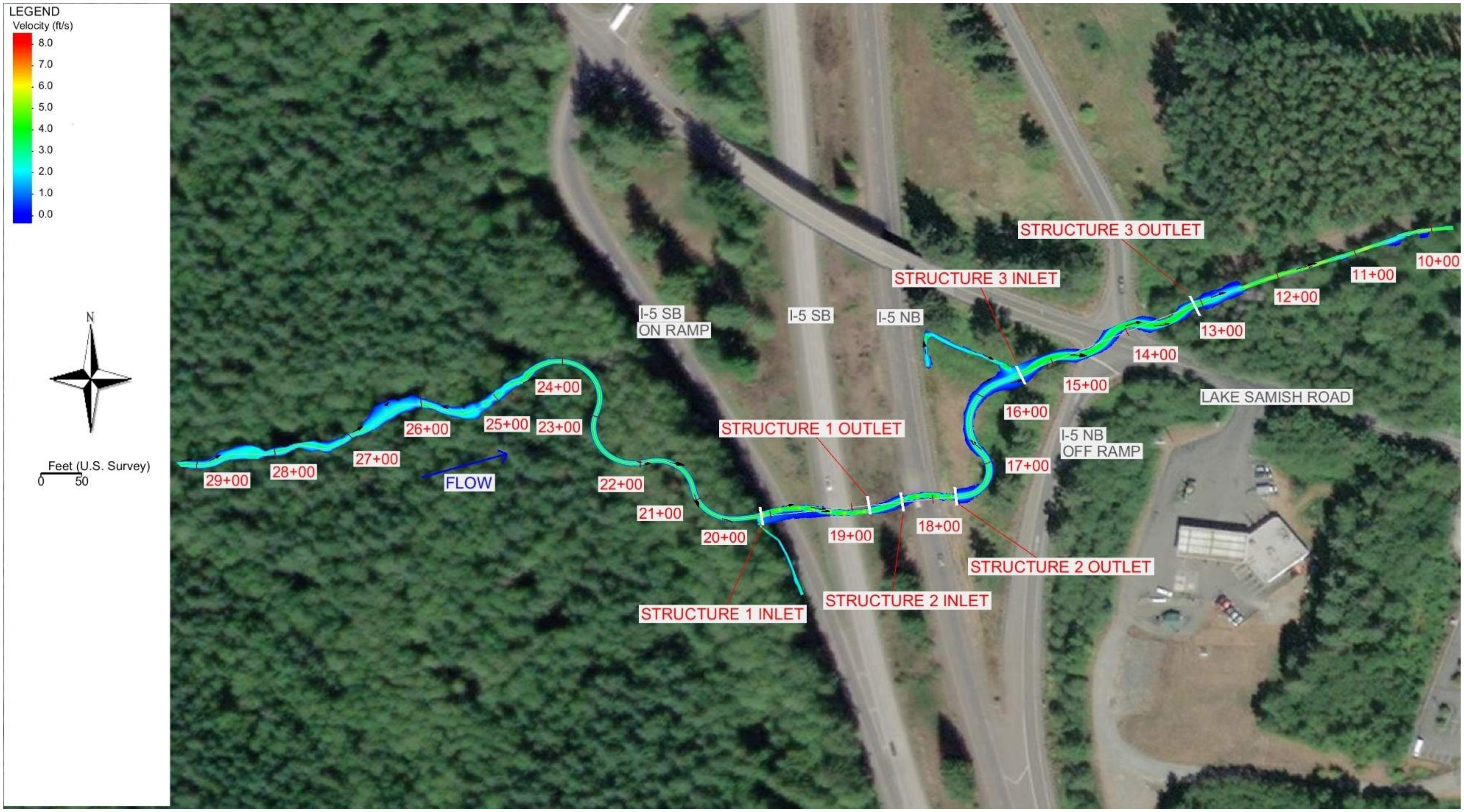
Proposed Conditions, 100-Year Flow, Shear Stress (psf)



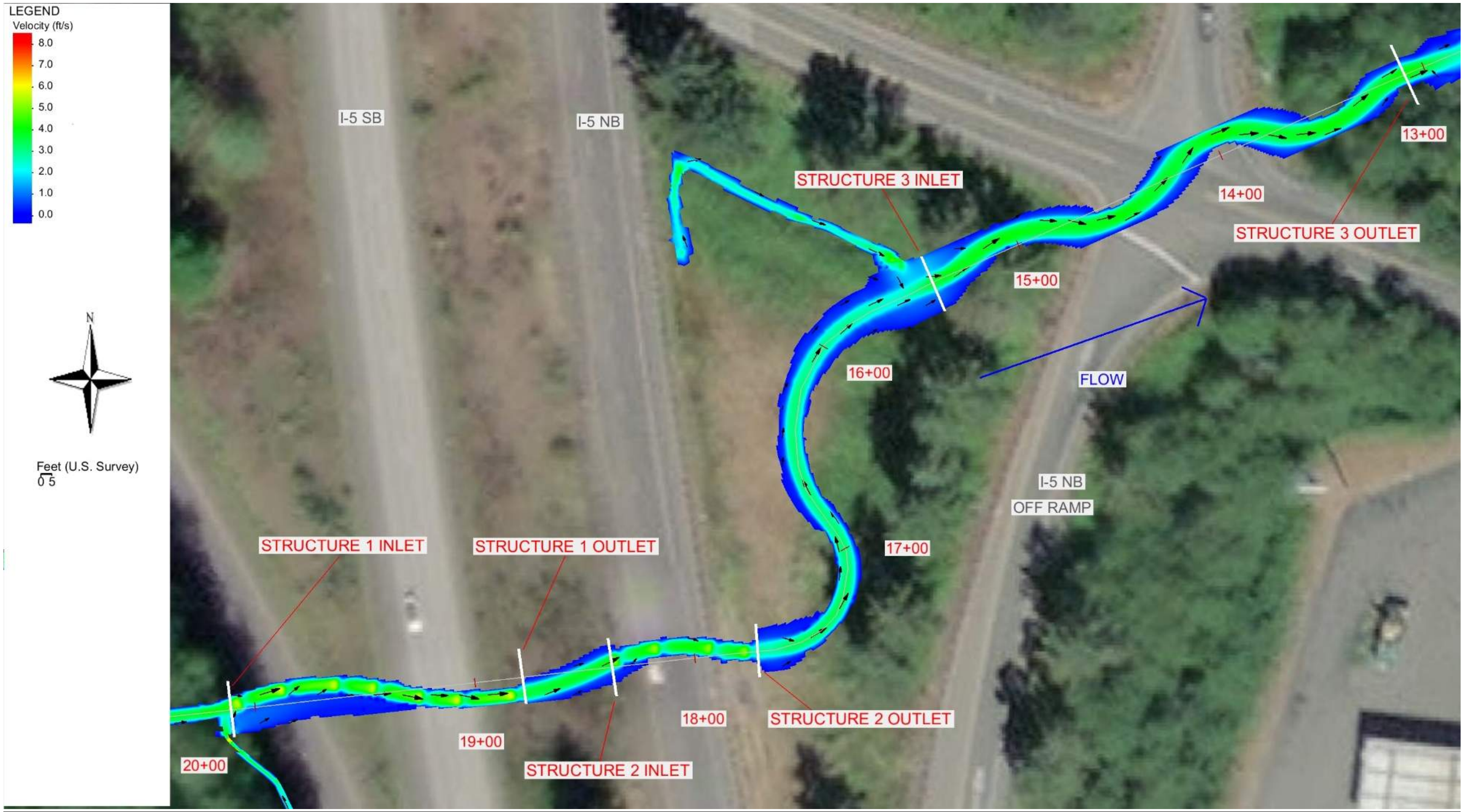
Proposed Conditions, Structure Crossings, 100-Year Flow, Shear Stress (psf)



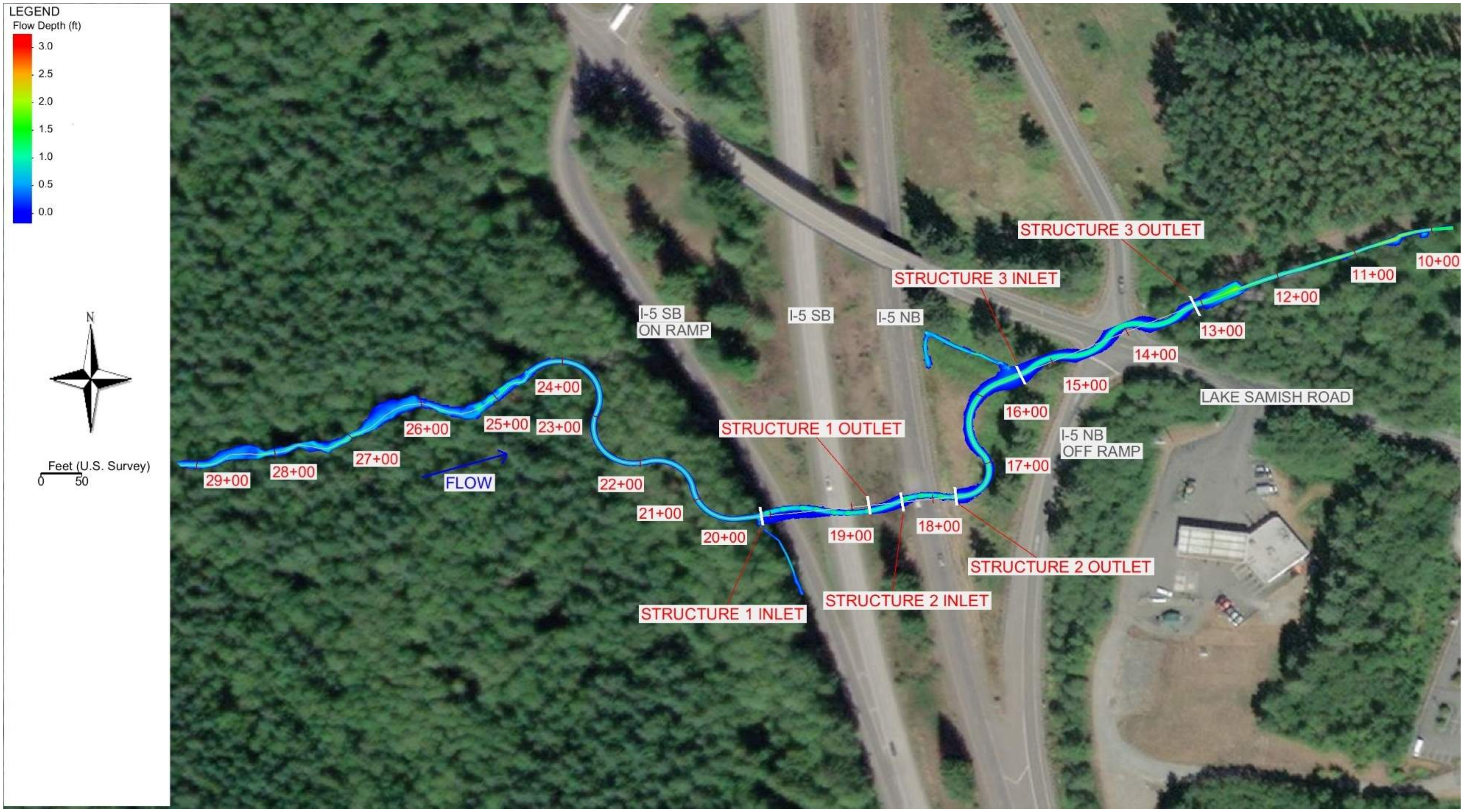
Proposed Conditions, 100-Year Flow, Velocity (ft/s)



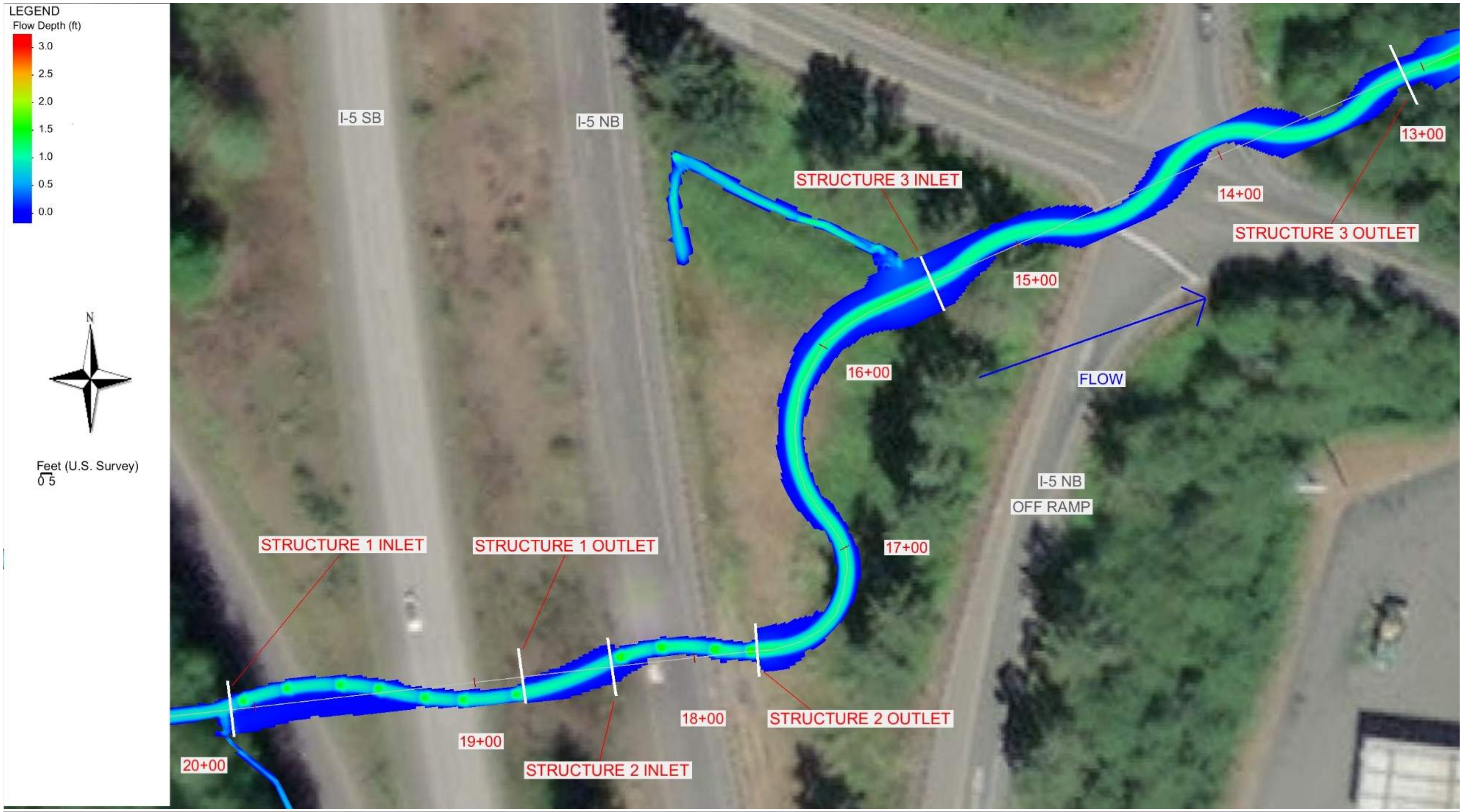
Proposed Conditions, Structure Crossings, 100-Year Flow, Velocity (ft/s)



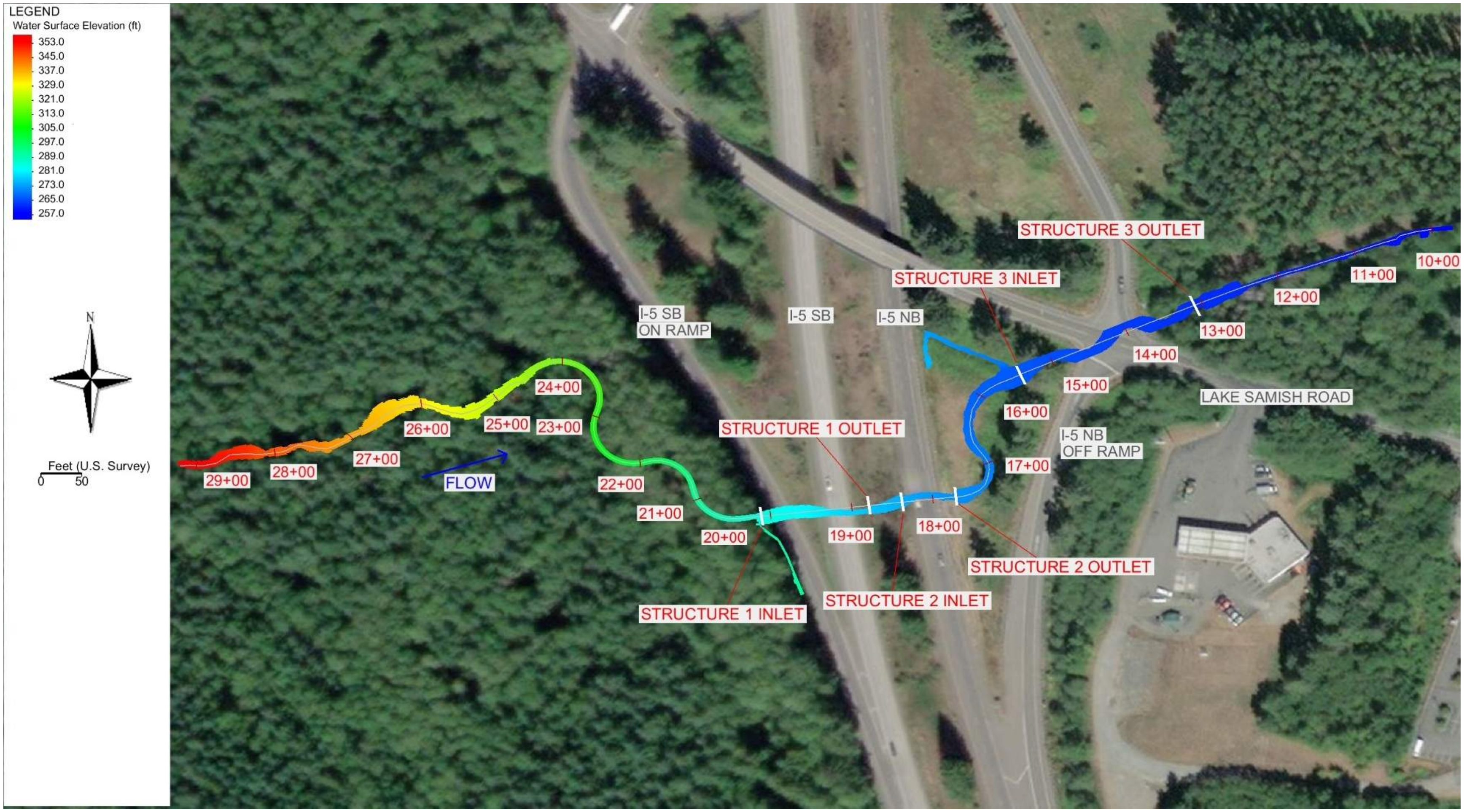
Proposed Conditions, 100-Year Flow, Flow Depth (ft)



Proposed Conditions, Structure Crossings, 100-Year Flow, Flow Depth (ft)

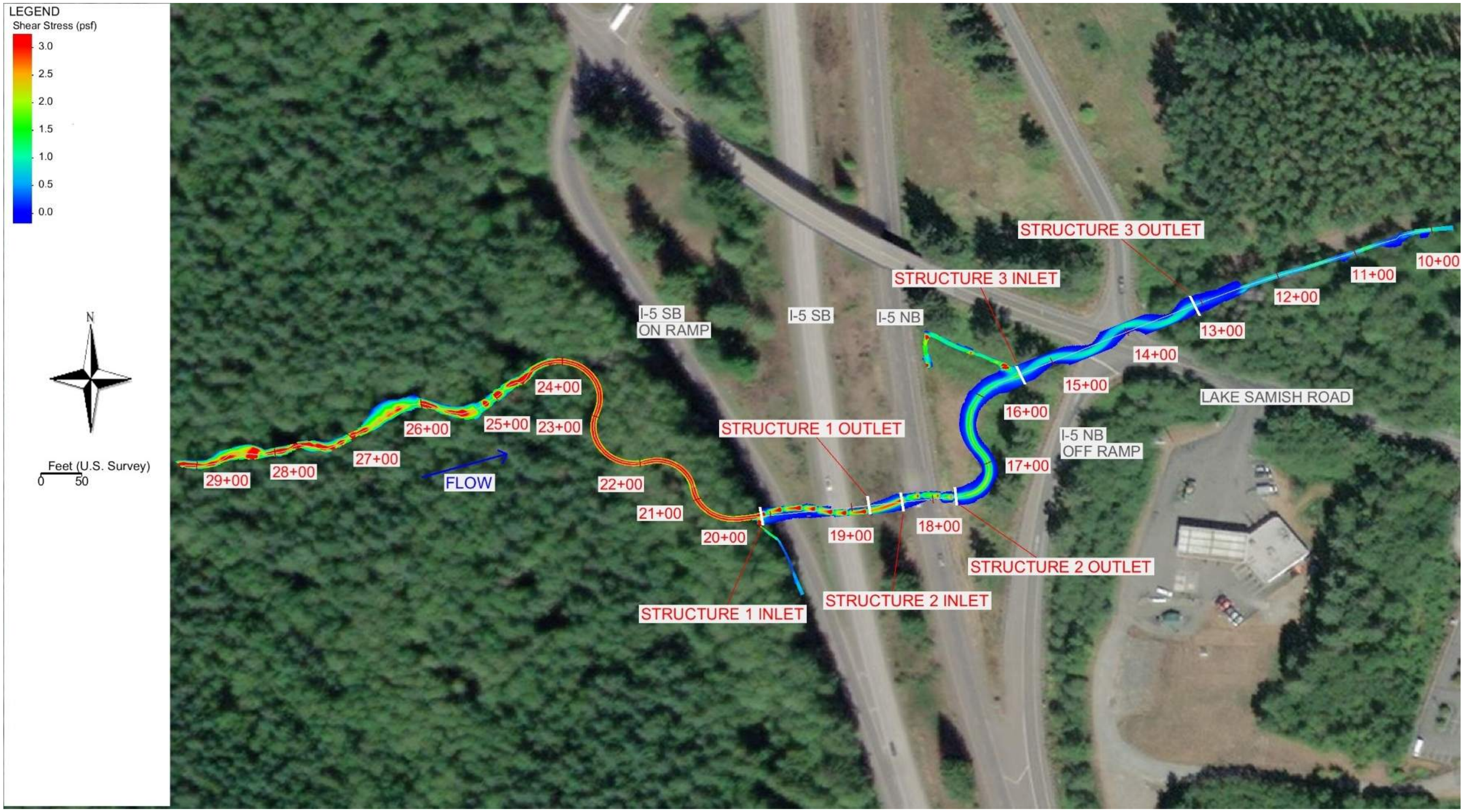


Proposed Conditions, 100-Year Flow, Water Surface Elevation (ft)

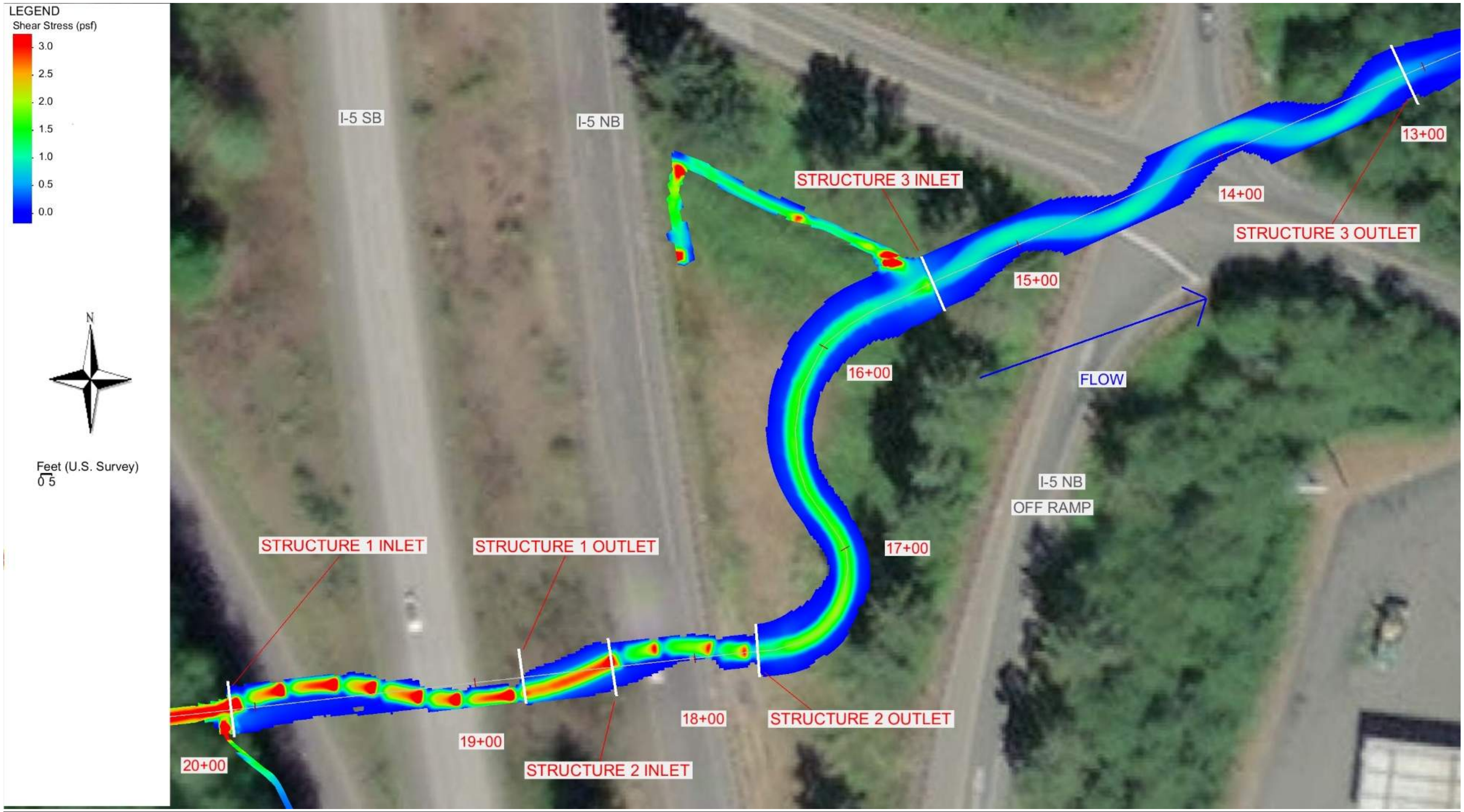


Proposed Conditions, Structure Crossings, 100-Year Flow, Water Surface Elevation (ft)

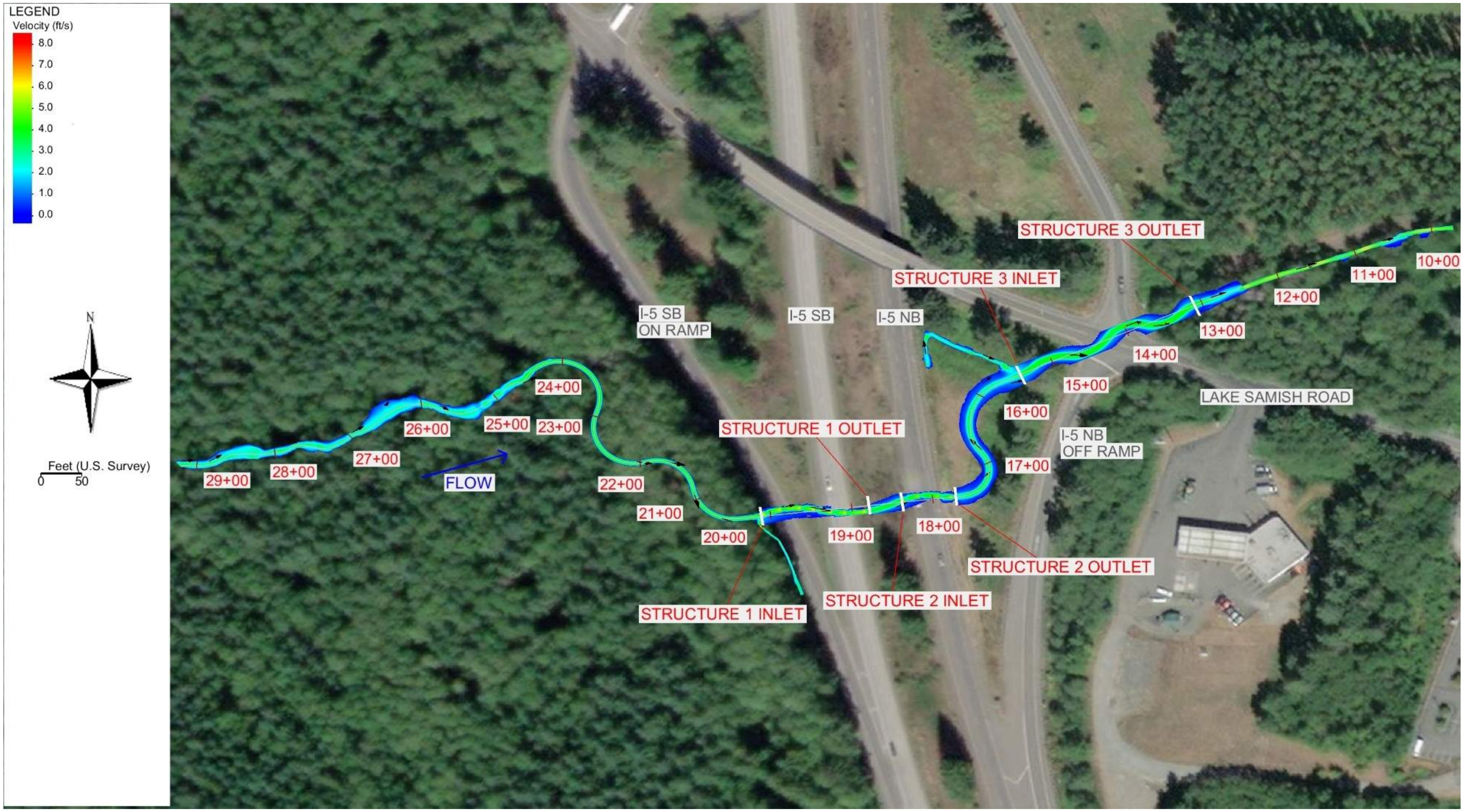
Proposed Conditions, 2080 100-Year Flow, Shear Stress (psf)



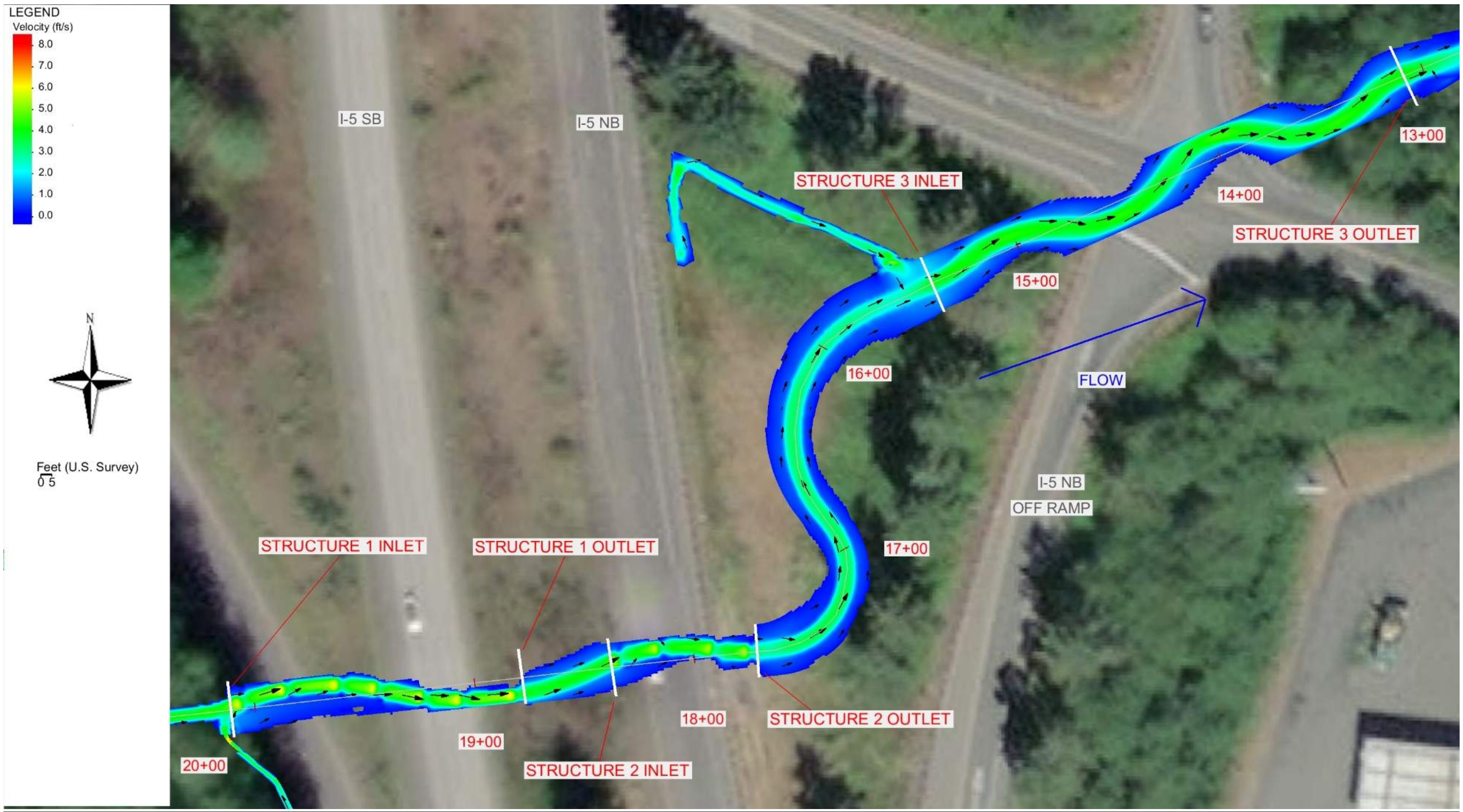
Proposed Conditions, Structure Crossings, 2080 100-Year Flow, Shear Stress (psf)



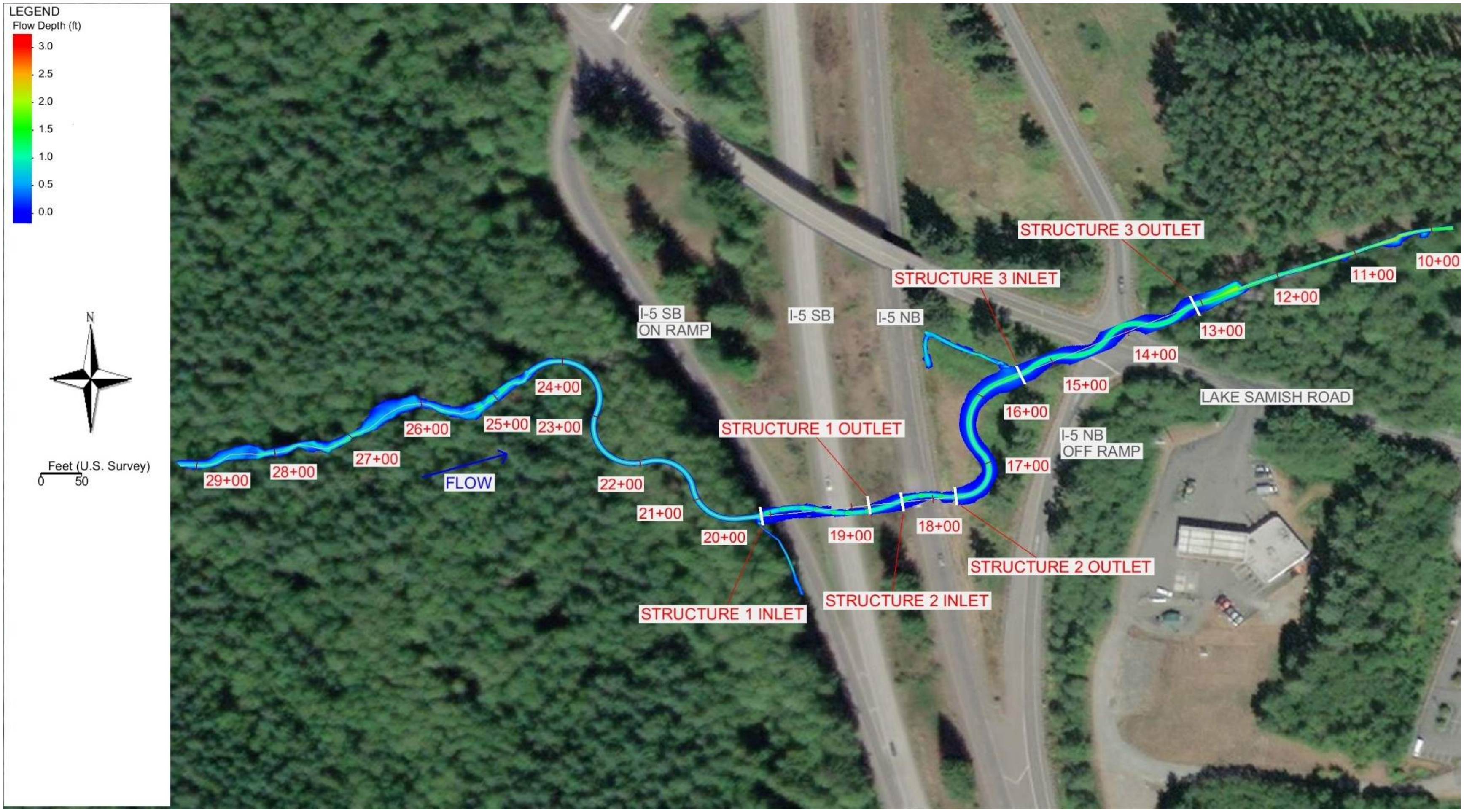
Proposed Conditions, 2080 100-Year Flow, Velocity (ft/s)



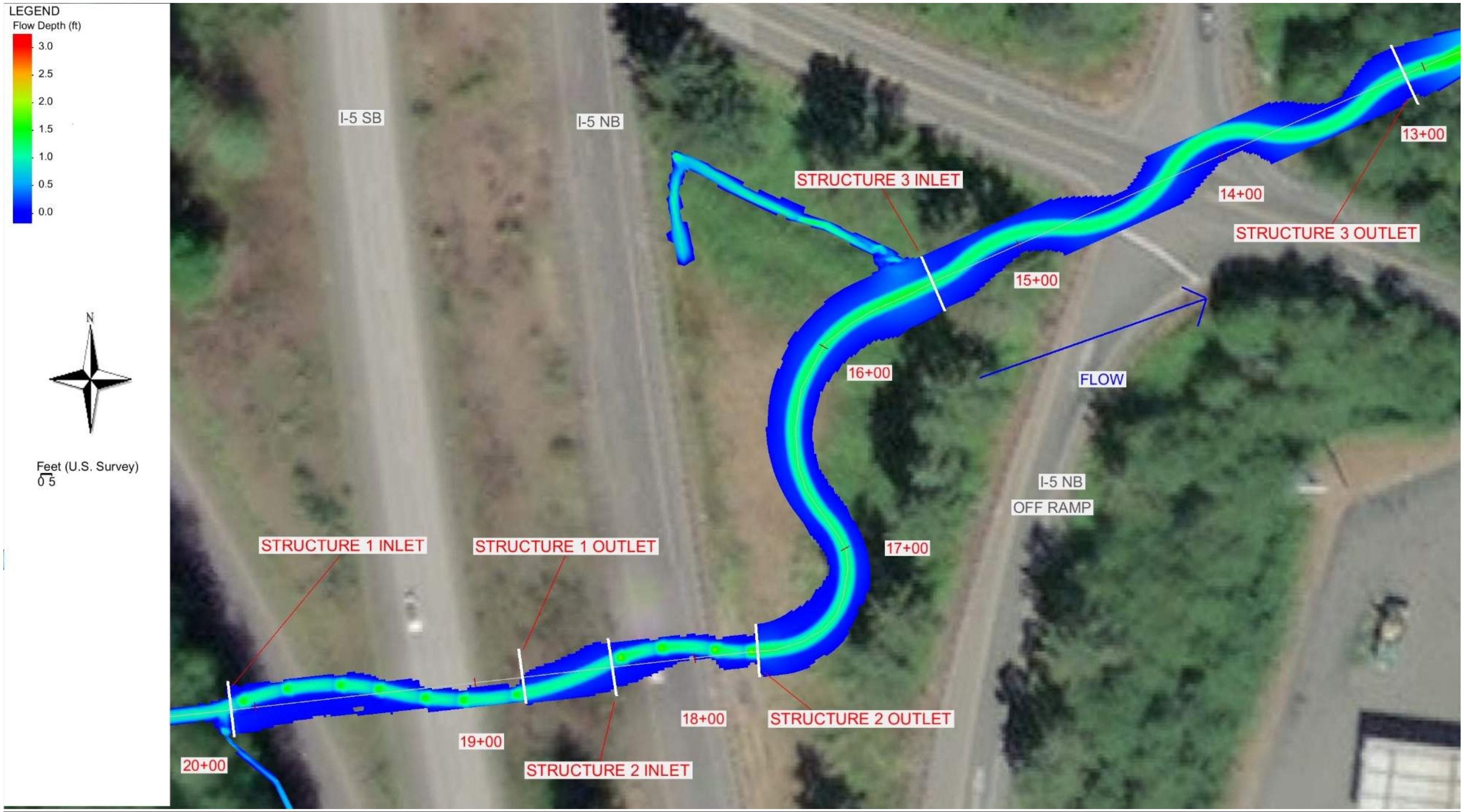
Proposed Conditions, Structure Crossings, 2080 100-Year Flow, Velocity (ft/s)



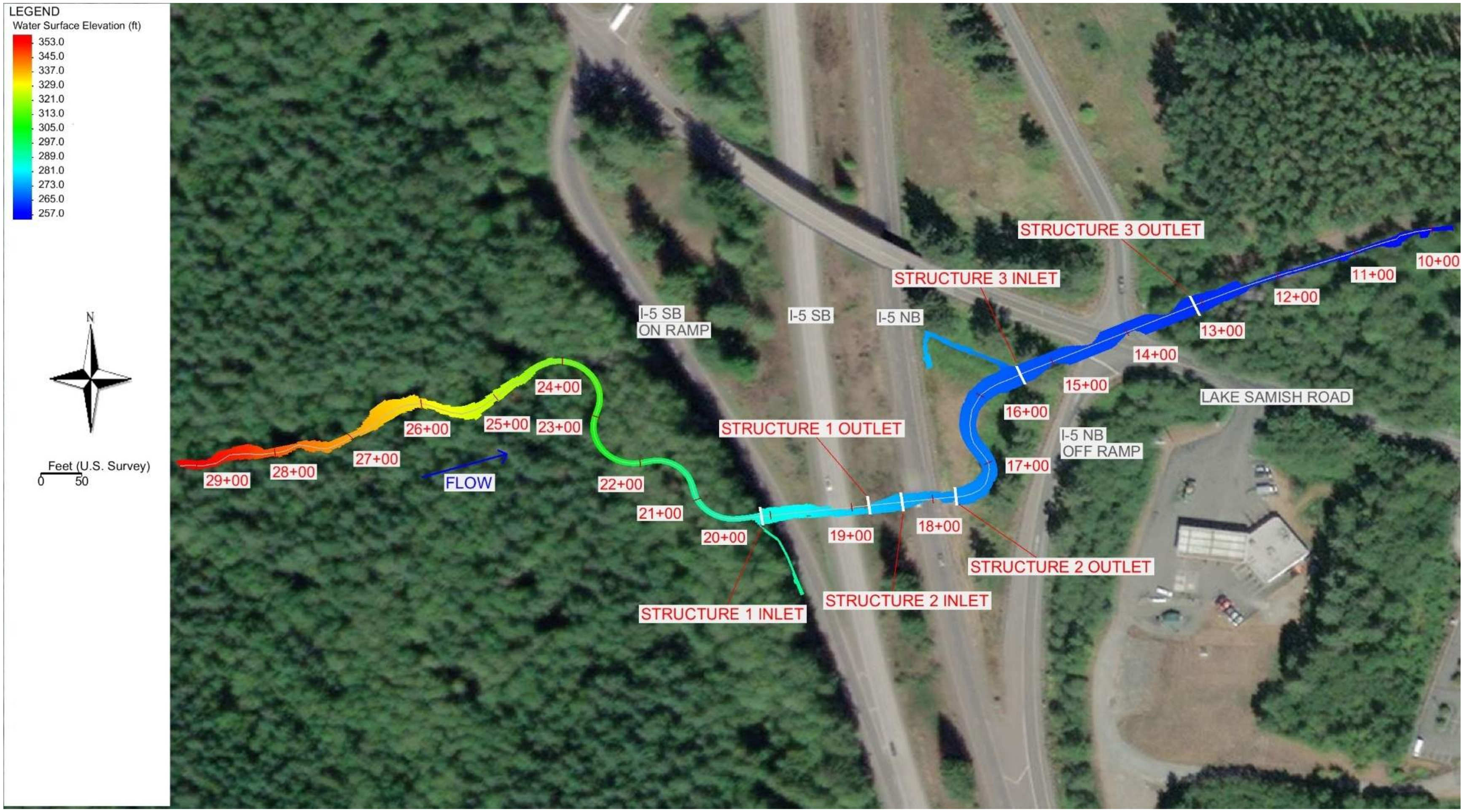
Proposed Conditions, 2080 100-Year Flow, Flow Depth (ft)



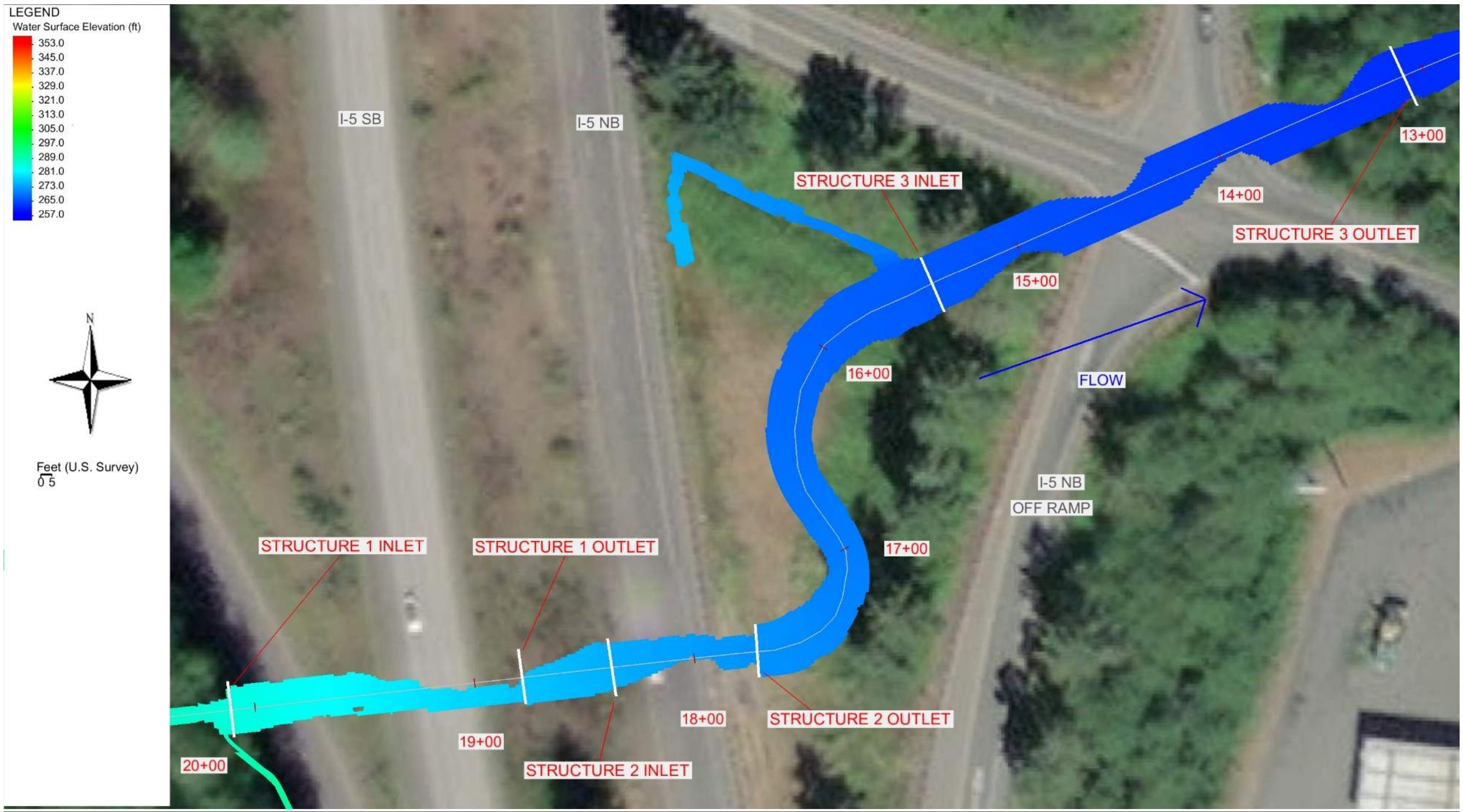
Proposed Conditions, Structure Crossings, 2080 100-Year Flow, Flow Depth (ft)



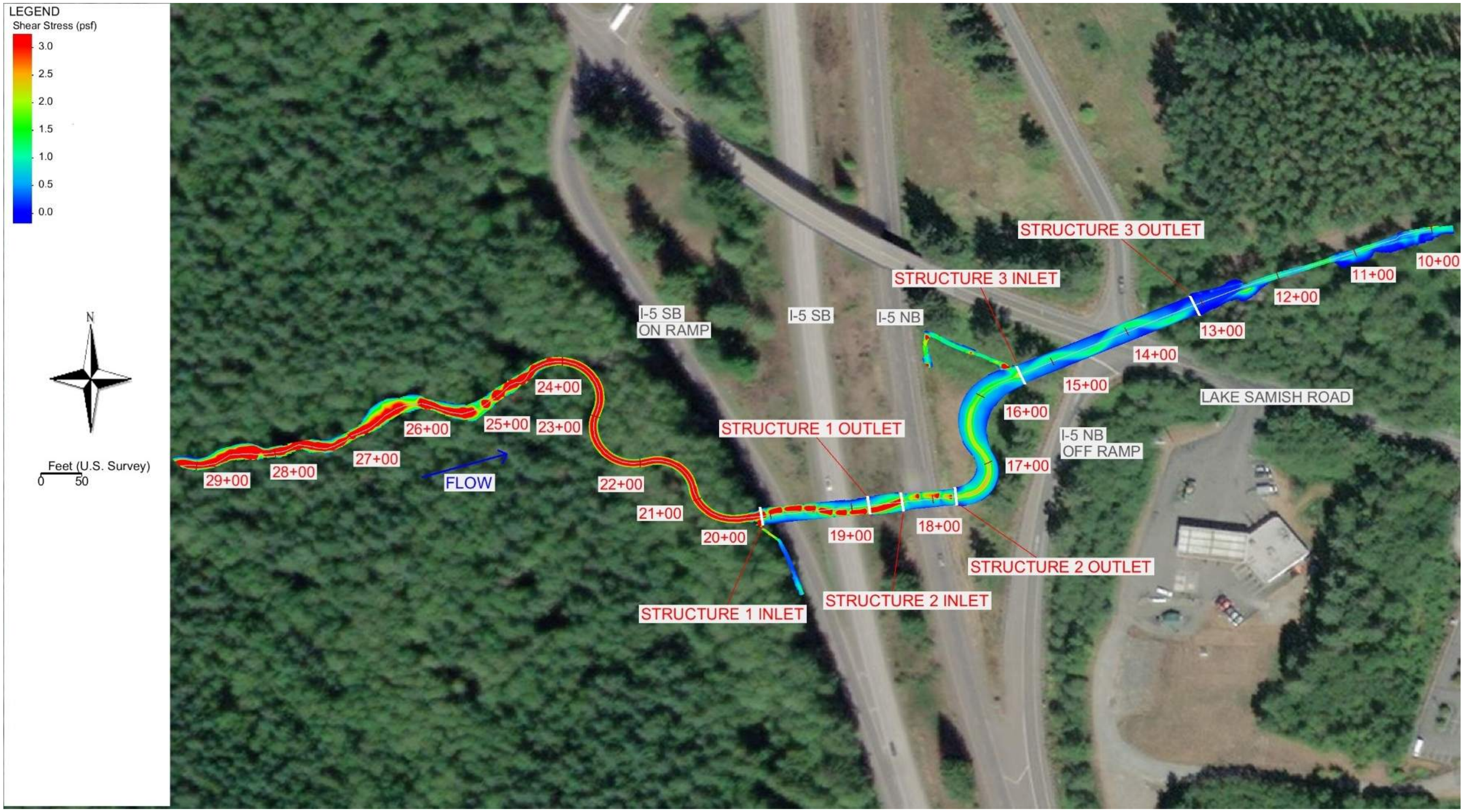
Proposed Conditions, 2080 100-Year Flow, Water Surface Elevation (ft)



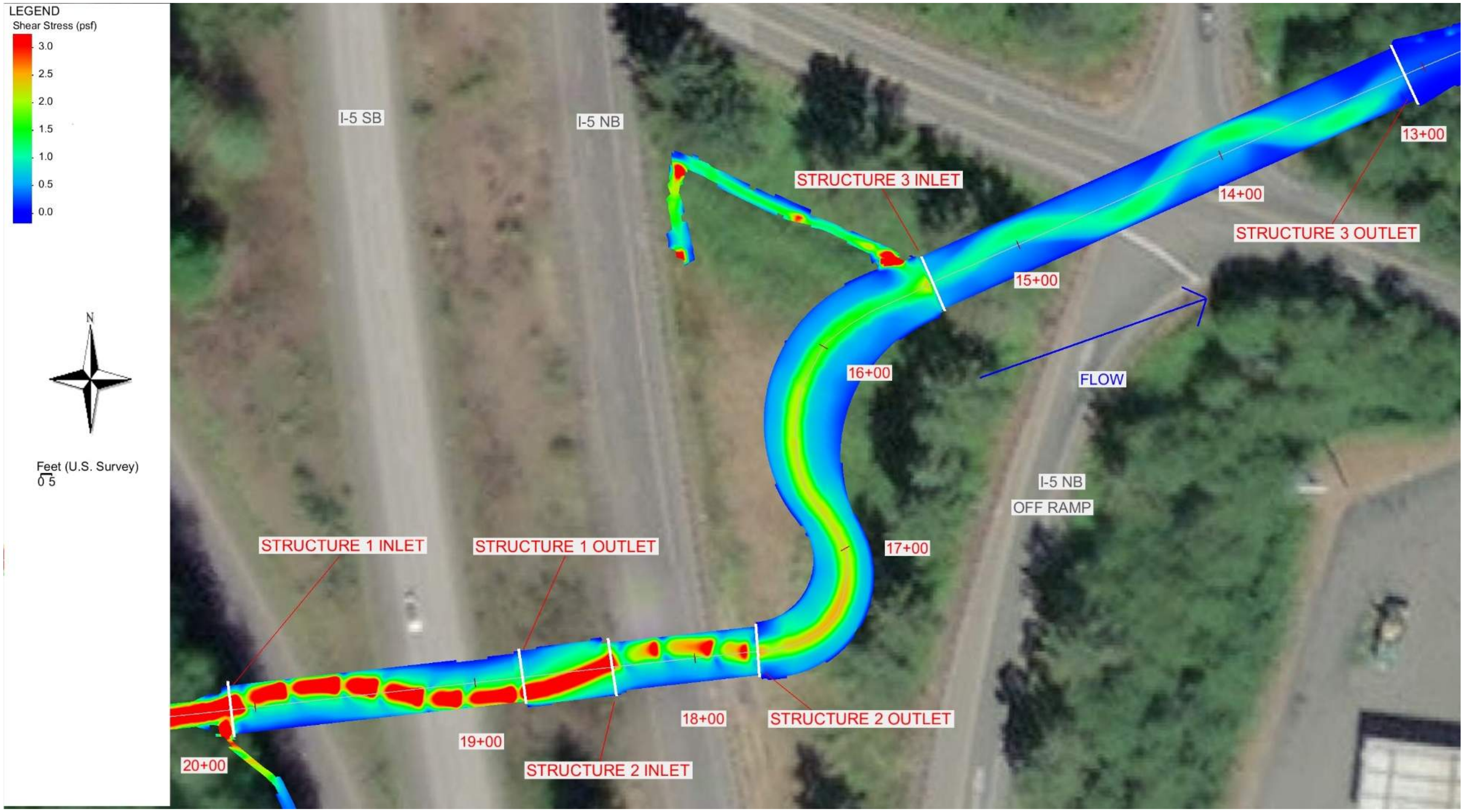
Proposed Conditions, Structure Crossings, 2080 100-Year Flow, Water Surface Elevation (ft)



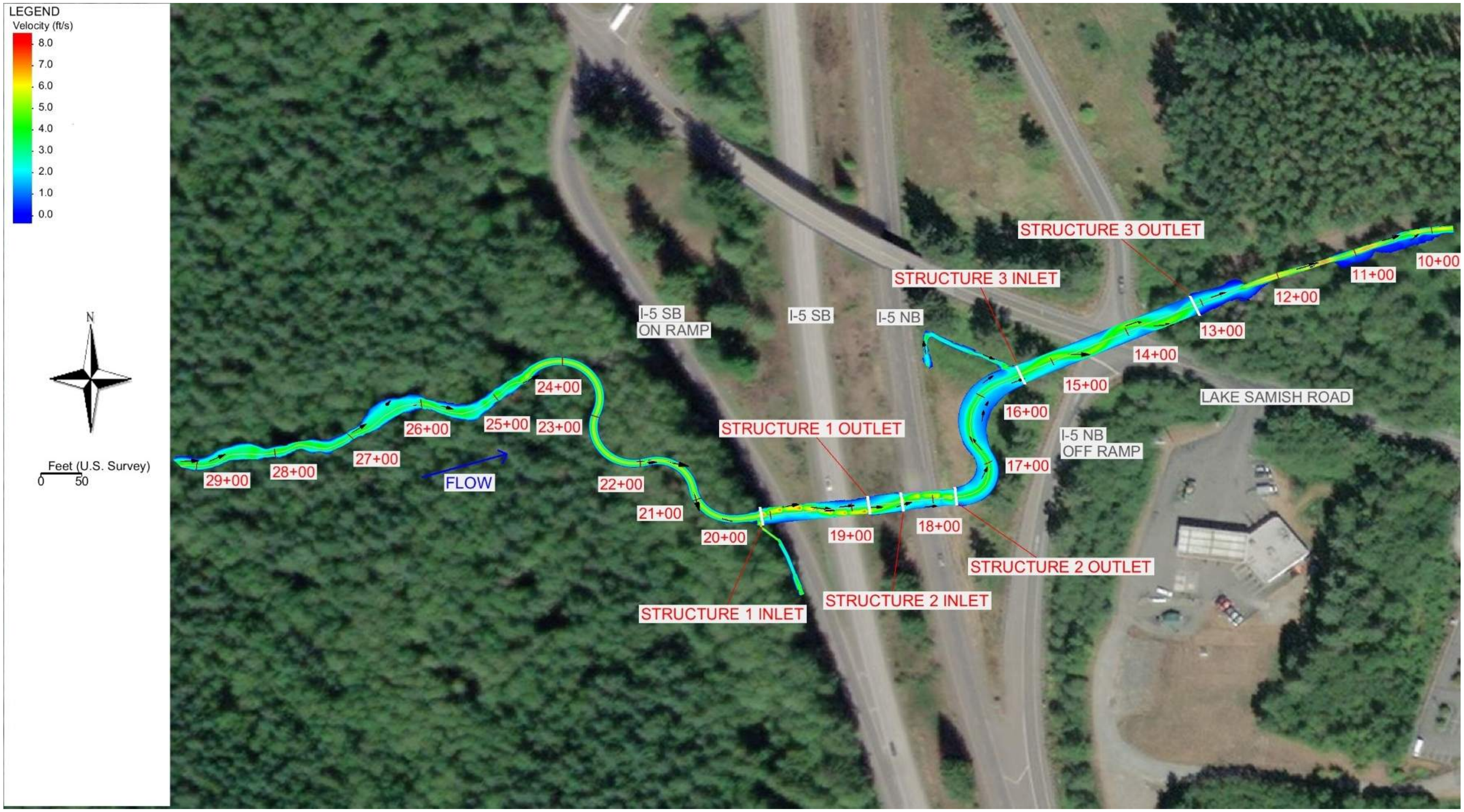
Proposed Conditions, 500-Year Flow, Shear Stress (psf)



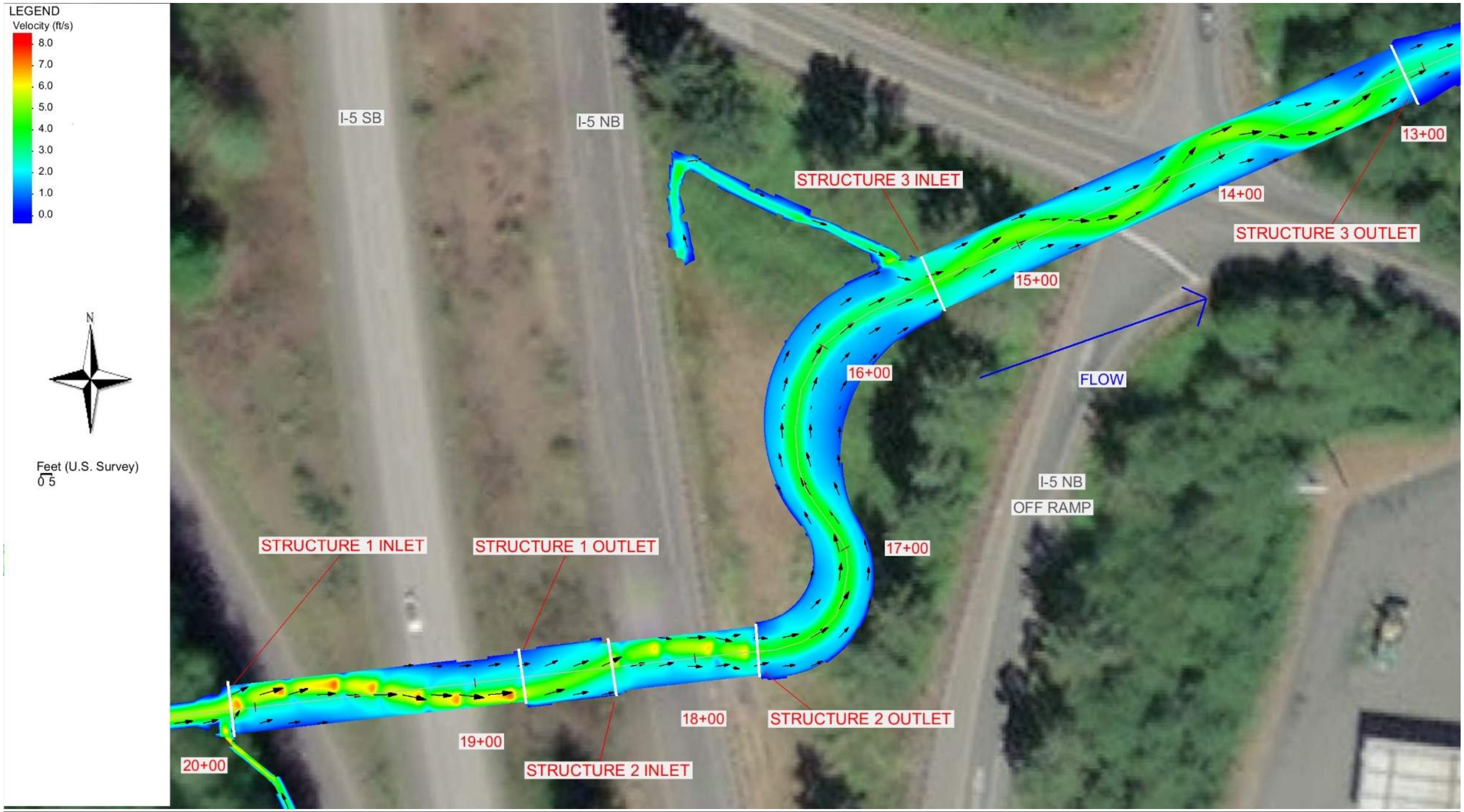
Proposed Conditions, Structure Crossings, 500-Year Flow, Shear Stress (psf)



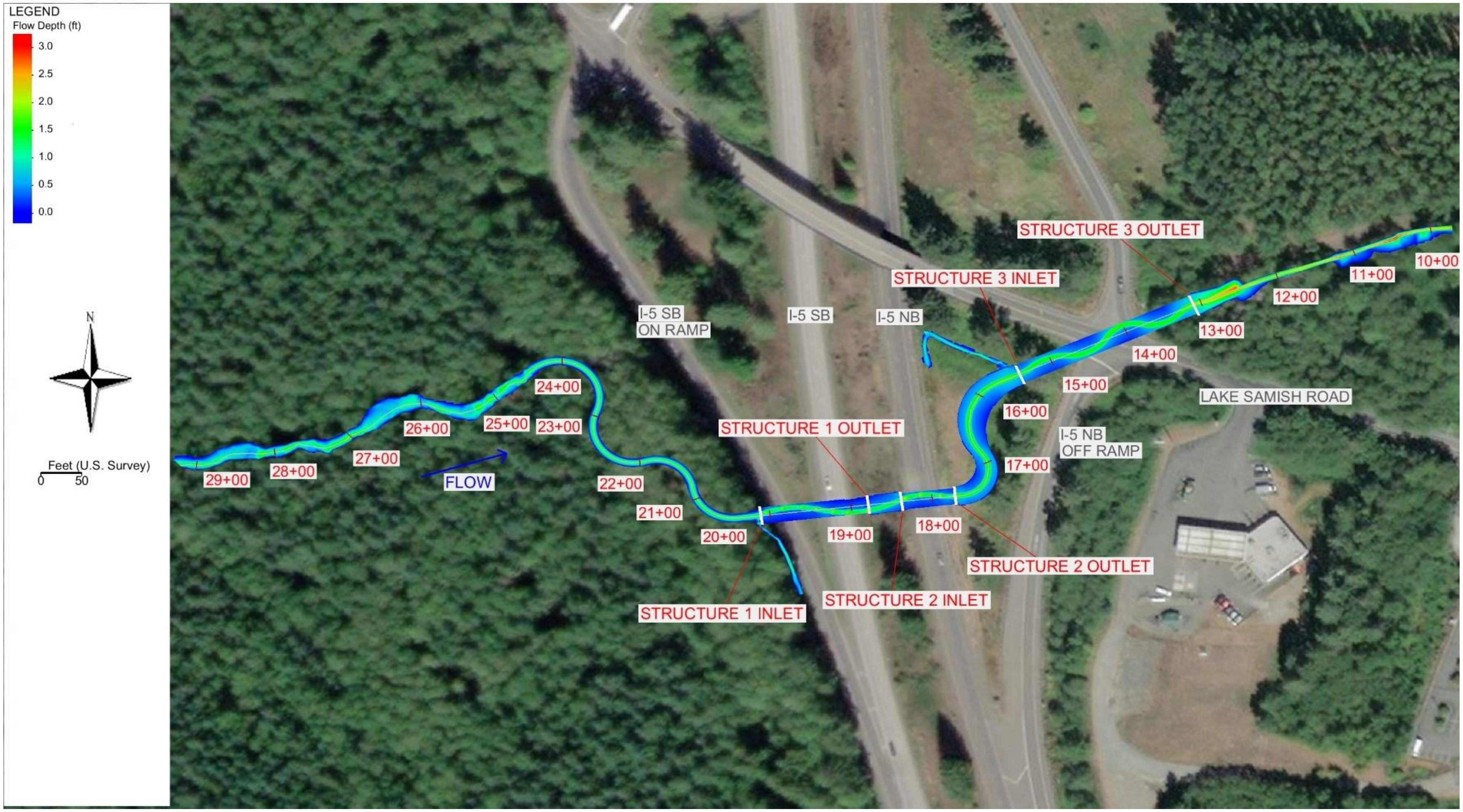
Proposed Conditions, 500-Year Flow, Velocity (ft/s)



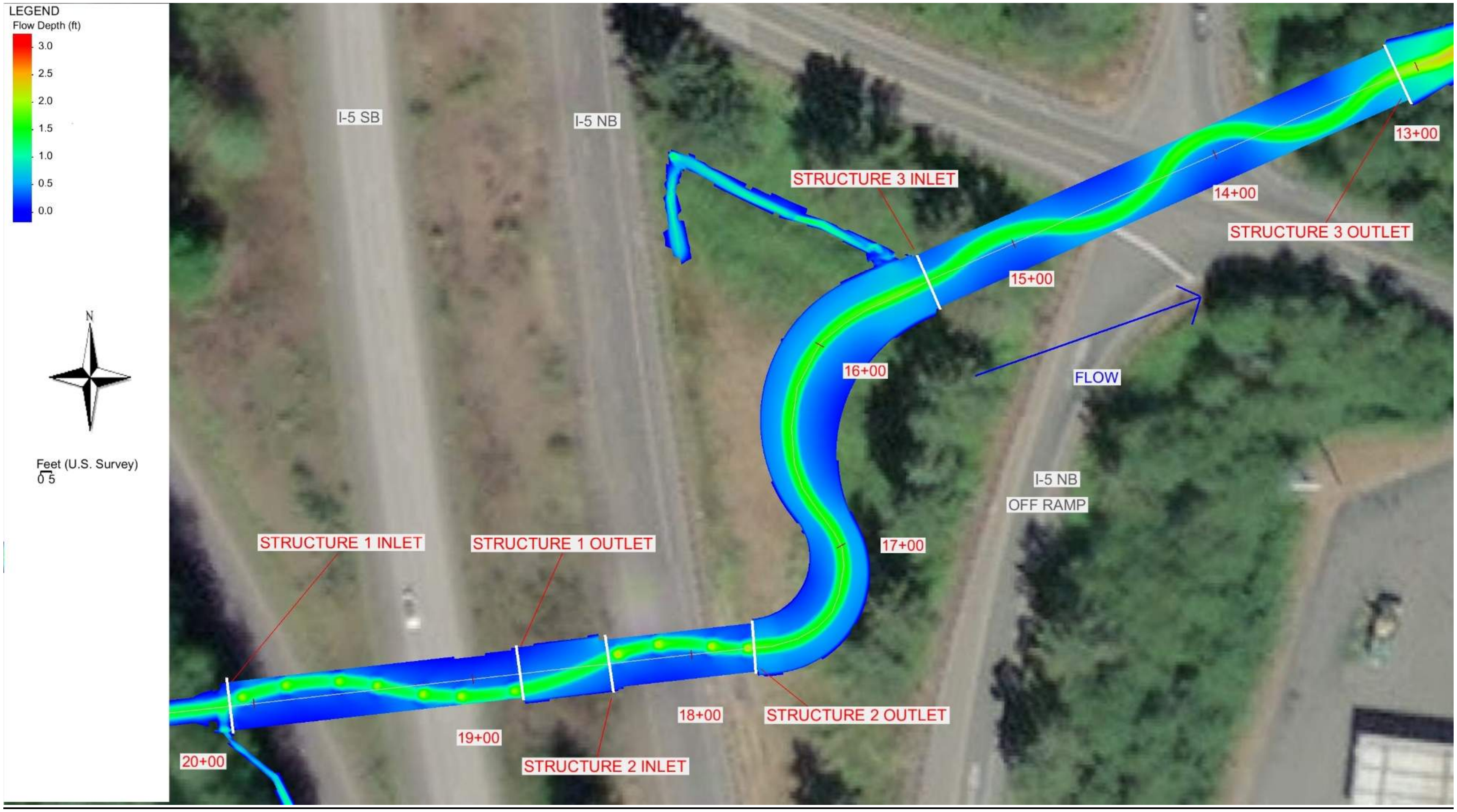
Proposed Conditions, Structure Crossings, 500-Year Flow, Velocity (ft/s)



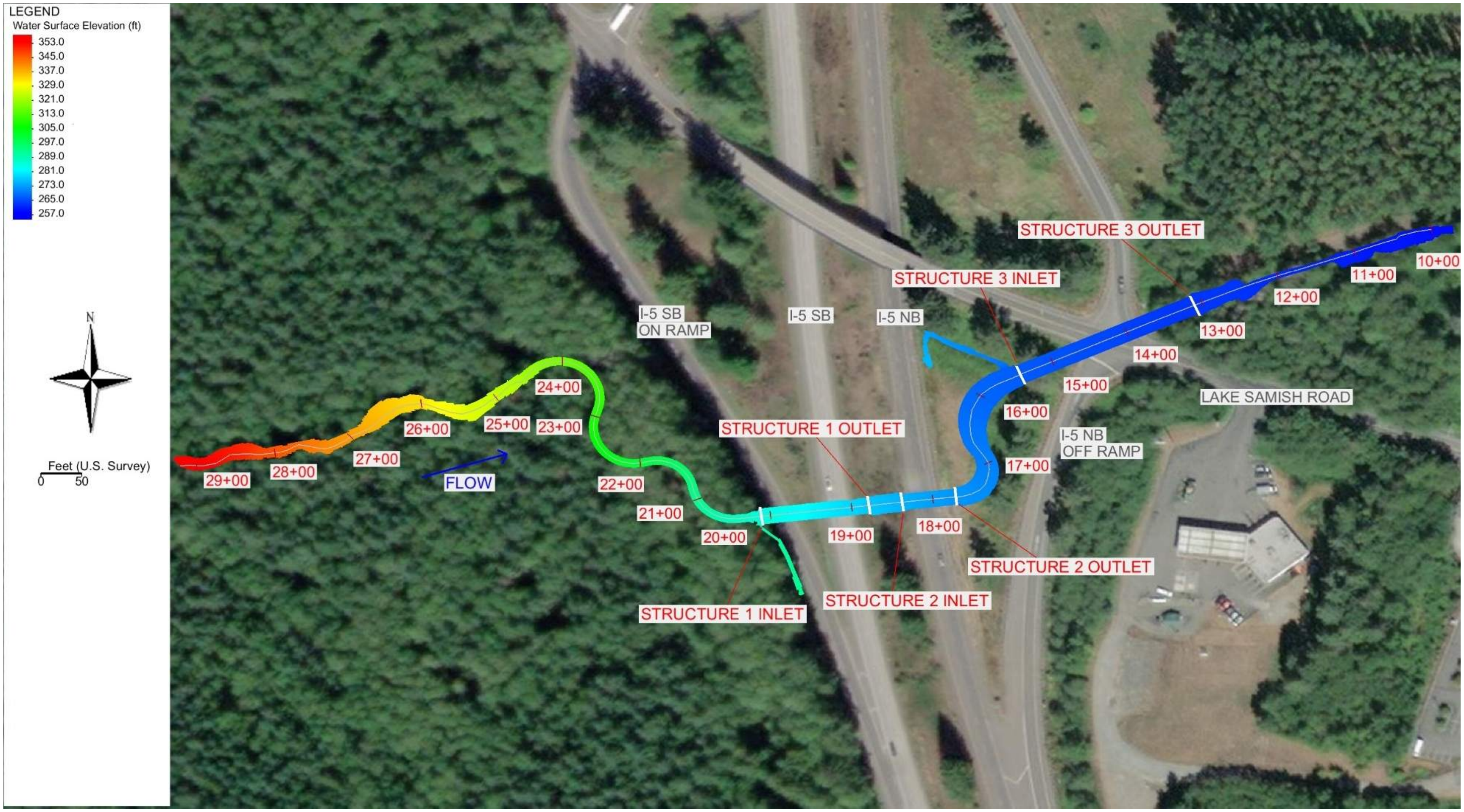
Proposed Conditions, 500-Year Flow, Flow Depth (ft)



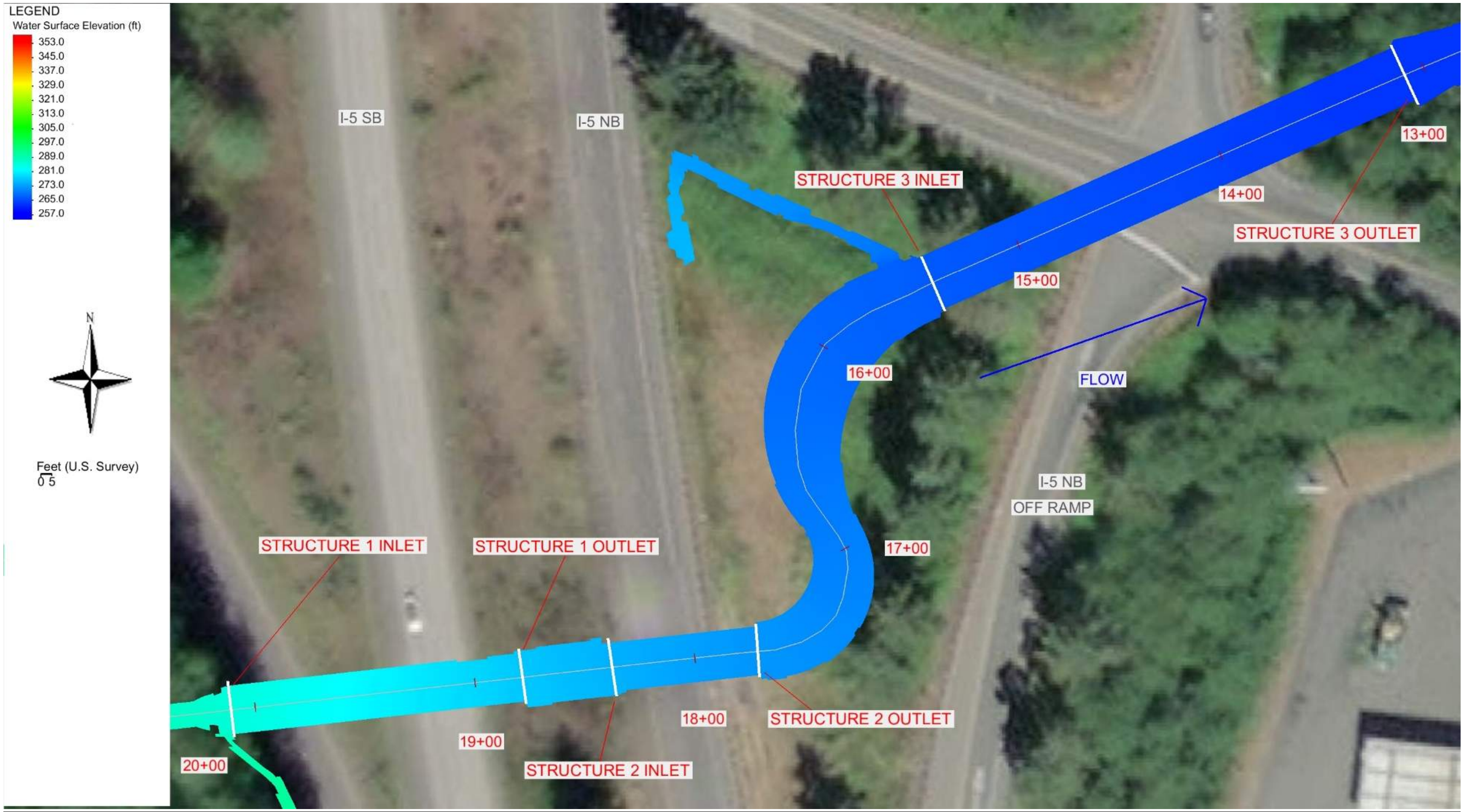
Proposed Conditions, Structure Crossings, 500-Year Flow, Flow Depth (ft)



Proposed Conditions, 500-Year Flow, Water Surface Elevation (ft)



Proposed Conditions, Structure Crossings, 500-Year Flow, Water Surface Elevation (ft)



Appendix D: Streambed Material Sizing Calculations

South Tributary to Friday Creek

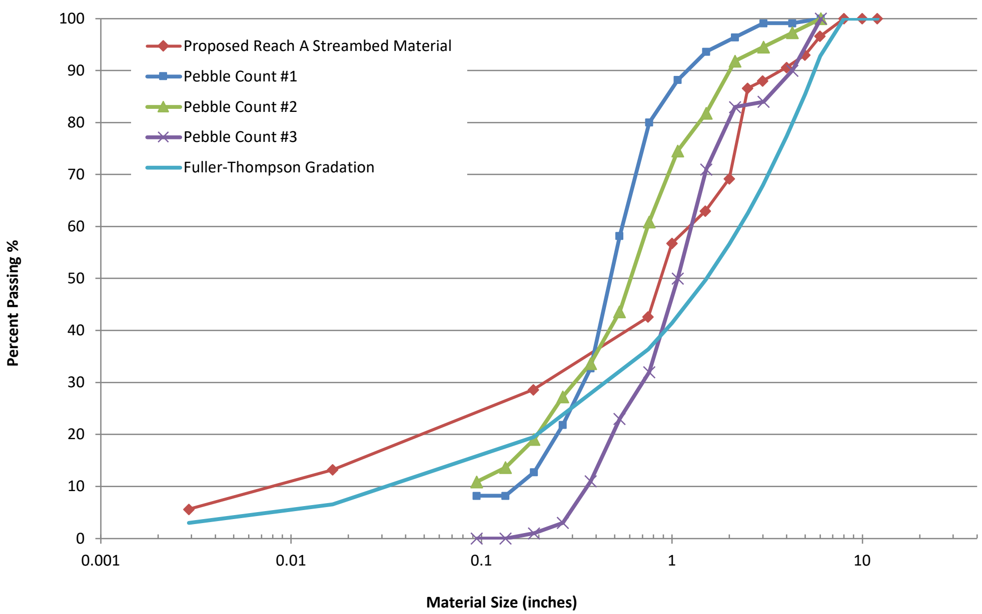
Proposed Reach A Streambed Material

Rock Size				Percent Passing (%)						
MM		Inches	Feet	WSDOT Streambed Sediment	WSDOT 4" Cobbles	WSDOT 6" Cobbles	WSDOT 8" Cobbles	WSDOT 10" Cobbles	WSDOT 12" Cobbles	Design Gradation (%)
304.8		12	1	100	100	100	100	100	100	**100**
254		10	0.83	100	100	100	100	100	83	**100**
203.2		8	0.67	100	100	100	100	83	65	**100**
152.4		6	0.5	100	100	100	83	65	53	**96.6**
127		5	0.42	100	100	83	65	53	40	**93**
101.6		4	0.33	100	100	65	53	40	35	**90.6**
76.2		3	0.25	100	84	57	40	34	29	**88**
63.5		2.5	0.21	100	65	48	33	27	24	**86.6**
50.8		2	0.17	80	51	40	26	21	18	**69.2**
38.1		1.5	0.13	74	35	30	19	15	13	**63**
25.4		1	0.08	68	23	20	12	8	7	**56.8**
19.05		0.75	0.06	52	10	10	5	2	2	**42.6**
4.7498	No.4	0.19		35	7	7	3	1	1	**28.6**
0.4191	No.40	0.017		16	3	3	2	1	1	**13.2**
0.07366	No.200	0.0029		7						**5.6**
			% Per Category	**80**			**20**			**100**

Note: 5% Minimum

	Design Gradation:		Observed Average Gradation		
	(IN)	(FT)	% Passing	(IN)	(FT)
D100	7.41	0.62	100	7.09	0.59
D84	2.43	0.202	84	2.17	0.181
D50	0.88	0.073	50	0.84	0.070
D16	0.05	0.00	16	0.31	0.03
DMIN	0.003	0.0002	0	0.08	0.0066

Design D50 / Observed D50 =	**1.04**



Washington State Department of Transportation

BED MATERIAL SIZING CALCULATIONS

Project:	South Tributary to Friday Creek Preliminary Hydraulic Design Report		
SR Route:	I-5	**Mile Post:**	MP 240.92 and 240.95
Stream Crossing:	South Unnamed Tributary to Friday Creek - Proposed Reach A		
Designer:	D. Stewart, Otak	**Date:**	4/19/2022
Checked By:			

References:

Bathurst, J.C. (1987) Critical Conditions for Movement in Steep Boulder-Bed Streams. Int. Assoc. of Hydraulical Sciences Pub. Vol. 165.

$$D_{84} = 3.45 * S^{0.747} * \frac{(1.25 * q_c)^{\frac{2}{3}}}{g^{\frac{1}{3}}} \qquad cfs = \frac{ft^3}{s}$$

Input Data

Cross Section Name/Station:			
Flow Event:		*100*	yr
Energy Slope (S) - ft/ft:	S =	*0.081*	ft/ft
100-yr Flow in Main Channel (Q):	Q =	*18.0*	cfs
Stream Width (W):	W =	*6.8*	ft
Specific Discharge (q_c) - (cfs/ft):	q_c =	*2.6*	ft^2/s

$$q_c = \frac{Q}{W}$$

$$D_{84} = 3.45 * S^{0.747} * \frac{(1.25 * q_c)^{\frac{2}{3}}}{g^{\frac{1}{3}}}$$

D_{84} = 0.37 ft, 4.42 in

$$D_{16} = \frac{D_{84}}{8}$$

D_{16} = 0.05 ft, 0.55 in

$$D_{50} = \frac{D_{84}}{2.5}$$

D_{50} = 0.15 ft, 1.77 in

$$D_{100} = \frac{D_{84}}{0.4}$$

D_{100} = 0.92 ft, 11.05 in

Input Data

Cross Section Name/Station:			
Flow Event:		*2*	yr
Energy Slope (S) - ft/ft:	S =	*0.081*	ft/ft
2-yr Flow in Main Channel (Q):	Q =	*3.8*	cfs
Stream Width (W):	W =	*6.8*	ft
Specific Discharge (q_c) - (cfs/ft):	q_c =	*0.6*	ft^2/s

$$q_c = \frac{Q}{W}$$

$$D_{84} = 3.45 * S^{0.747} * \frac{(1.25 * q_c)^{\frac{2}{3}}}{g^{\frac{1}{3}}}$$

D_{84} =	0.13	ft
	1.57	in

$$D_{16} = \frac{D_{84}}{8}$$

D_{16} =	0.02	ft
	0.20	in

$$D_{50} = \frac{D_{84}}{2.5}$$

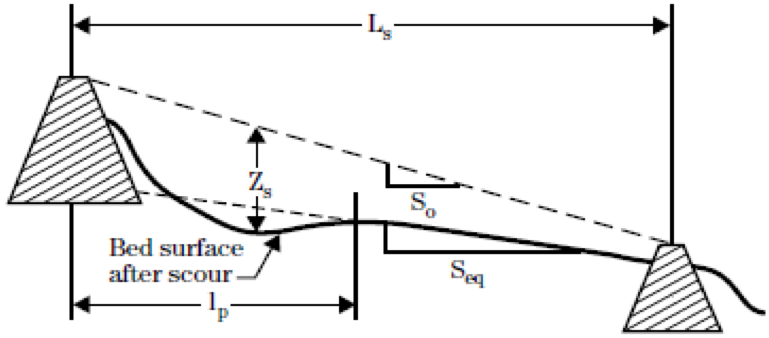
D_{50} =	0.05	ft
	0.63	in

$$D_{100} = \frac{D_{84}}{0.4}$$

D_{100} =	0.33	ft
	3.92	in

South Tributary to Friday Creek

Boulder Step Design



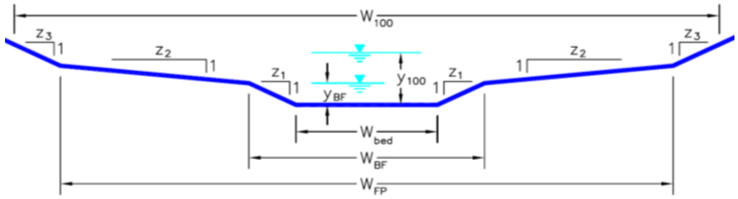
Cascade Design Parameters	Symbol	Value	Units	Notes
Width - Cascade Bed	W_C	4.00	ft	
Width - Cascade Banks	W_C	6.80	ft	
(H:1) - Cascade Bank Slopes	z_1	2.00	__ ft : 1 ft	
Number of Cascade Structures	N_C	1.00	ea	Crest to d/s controlling bed elevation
Distance Between Cascades	L_s	18.00	ft	Distance between cascade crests
Cascade Drop Height	h_d	0.52	ft	Crest to d/s controlling bed elevation
Design Gradient of Cascade Face	S_c	0.500	ft/ft	Design slope of cascade
Gradient between Cascade Crests	S_o	0.063	ft/ft	Design slope between cascade crests
Design Median Grain Size	D_{50}	1.00	ft	Median size of boulders in cascade

Cascade Hydraulic Parameters	Symbol	Value	Units	Notes
Max Depth of Flow in Cascade	y	0.70	ft	Conveys Q_{100}
Wetted Perimeter of Cascade	P	7.13	ft	
Area of Cascade	A	3.78	ft^2	
Hydraulic Radius (R = A / P)	R	0.53	ft	
Manning's Roughness Coefficient	n	0.088	-	
Calculated Maximum Discharge	Q_C	29.4	cfs	Calculated Q_C should be ≈ Q_{100}
Calculated Velocity (V = Q / A)	V_C	7.78	ft/s	
Froude Number (Fr < 1, subcritical)	Fr	1.64	-	
Shear Stress	τ	16.54	lb/ft^2	
100-yr Unit Discharge	q_{100}	2.65	cfs / ft	$q_{100} = Q_{100} / W_c$
Specific Energy of Critical Flow	H_s	0.90	ft	Calculated at crest of cascade
Target Median Grain Size (FS=1.5)	$D_{50,min}$	0.94	ft	ARS Rock Chute Method

Cascade Design Verification	Design	Target	Units	Check
Can the proposed cascade channel convey Q_{100}?	29.4	18.0	cfs	Yes
Is the design Median Grain Size ≥ Target Median Grain Size?	1.00	0.94	ft	Yes

South Tributary to Friday Creek

Proposed Reach A Boulder Step Stability Calculation



Design Equations (Reference: USDA, NRCS, 2007. NEH part 654: Stream Restoration Design Guide)

[1] Hydraulic Radius: $R = A / P$

[2] Mannings Roughness Coefficient:

Limerinos ($R/D_{84} \geq 4$) $n = (0.0926 * R^{1/6}) / (1.16 + 2 \log (R/D_{84}))$

Mussetter ($R/D_{84} < 4$) $n = (1.486 * R^{1/6}) / (SQRT(g) * 1.11 * (R/D_{84})^{0.46} * (D_{84}/D_{50})^{-0.85} * S^{-0.39})$

[3] Discharge: $Q = (1.486 / n) * A * R^{2/3} * S^{1/2}$

[4] Velocity: $V = Q / A$

[5] Froude Number: $Fr = V / SQRT(g * y)$

[6] Shear Stress: $\tau = \gamma * R * S$

[7] Dimensionless Particle Size: $D_* = D_{50} (1.65g / v^2)^{1/3}$

[8] Critical Dimen. Shields Stress: $\theta_c = (0.24/D_*) + 0.055 [1 - \exp(-0.02D_*)]$

[9] Dimensionless Shear Stress: $\theta = (R*S) / (S_g*D_{50})$

[10] Minimum required D_{50}: Shields Method: $D_{50} = (R * S) / (1.65\ \theta_c)$

Channel Geometry Design and Target Substrate

Channel Design Parameters	Symbol	Units	Value	Notes
Width - Channel Bed	W_{bed}	ft	5.00	
Width - Bankfull	W_{BF}	ft	7.40	
Width - Floodplain	W_{FP}	ft	28.00	
(H:1) - Channel Bank Slope	z_1	__ ft : 1 ft	2.00	
(H:1) - Floodplain Slope	z_2	__ ft : 1 ft	50.00	
(H:1) - High Bank Slope	z_3	__ ft : 1 ft	3.00	
Design Gradient of Channel	S	ft/ft	0.0633	
Design Median Grain Size	D_{50}	ft	0.94	
Design 84th Percentile Grain Size	D_{84}	ft	2.35	WDFW Guidance: D84=2.5*D50 (Equation 3.7 in 2013 Water Crossing Design Guidelines)

Channel Hydraulic Analysis

Channel Hydraulic Parameters	Symbol	Units	2-YR Flow	100-YR Flow	Notes
Depth	y	ft	0.38	0.64	
Wetted Perimeter	P	ft	6.70	7.86	
Area	A	ft^2	2.19	4.02	
Hydraulic Radius	R	ft	0.33	0.51	[Eq. 1]
Relative Submergence	R/D_{84}	-	0.14	0.22	
Manning's Roughness Coefficient	n	-	0.050	0.050	
Calculated Discharge	Q	cfs	7.8	19.2	[Eq. 3]
Calculated Velocity	V	ft/s	3.55	4.78	[Eq. 4]
Froude Number (Fr < 1, subcritical)	Fr	-	1.01	1.05	[Eq. 5]
Shear Stress	τ	lb/ft^2	1.29	2.02	[Eq. 6]
Dimensionless Particle Size	D_*	-	6,054.7	6054.7	[Eq. 7]
Critical Dimensionless Shields Stress	θ_c	-	0.055	0.055	[Eq. 8]
Dimensionless Shear Stress	θ	-	0.013	0.021	[Eq. 9]
Target Median Grain Size	$D_{50,min}$	ft	0.23	0.36	[Eq. 10]

Channel Geometry Design Summary

Design Parameters	Symbol	Units	Value	Notes
Bed Width	W_{bed}	ft	5.00	
Top Width - Bankfull	W_{BF}	ft	7.40	
Top Width - Floodplain	W_{FP}	ft	28.00	
Flow Depth - Q2	y_2	ft	0.38	
Flow Depth - Q_{100}	y_{100}	ft	0.64	
Minimum Grain Size	D_{min}	in	sand	Need 5% to 10% fines
16th Percentile Grain Size	D_{16}	in	3.5	$D_{16} = D_{84} / 8$
Median Grain Size	D_{50}	in	11.3	
84th Percentile Grain Size	D_{84}	in	28.2	$D_{84} = (2.5) * D_{50}$
Maximum Grain Size	D_{max}	in	71.0	$D_{max} = D_{84} /0.4$

Modified Shields Calculation for Streambed Mobility
South Tributary - Proposed Reach A (> 4 % slope)
Otak, April 2022

Table A.1. Existing Conditions Upstream Reach

		Hydraulics						Particle Mobility / Stability					
Cross Section	Recurrence Interval	Discharge, Q (ft3/s)	Channel n value	Energy Slope Se	Channel Flow Width, Wc (ft	Channel Hydraulic Radius, Rc (ft)	Channel boundary shear stress Tc (lb/ft2)	D50 (feet)	D84 (feet)	Angle of repose	Shield's entrainment for D50, T50	Critical Shear stress to entrain D84 particle size, Tc-84 (lb/ft2)	D84 Particle mobile (yes/no)
2120	2 YR	3.7	0.11	0.1066	5.87	0.3322	2.210	0.070	0.181	38	0.047	0.450	**Yes**
2120	25 YR	14.5	0.11	0.1053	6.65	0.5504	3.615	0.070	0.181	38	0.047	0.450	**Yes**
2120	50 YR	16.32	0.11	0.1039	8.43	0.6610	4.286	0.070	0.181	38	0.047	0.450	**Yes**
2120	100 YR	17.63	0.11	0.1028	7.14	0.6101	3.913	0.070	0.181	38	0.047	0.450	**Yes**

Table A.2. Proposed Conditions Reach A - Structure 1

		Hydraulics						Particle Mobility / Stability					
Cross Section	Recurrence Interval	Discharge, Q (ft3/s)	Channel n value	Energy Slope Se	Channel Flow Width, Wc (ft	Channel Hydraulic Radius, Rc (ft)	Channel boundary shear stress Tc (lb/ft2)	D50 (feet)	D84 (feet)	Angle of repose	Shield's entrainment for D50, T50	Critical Shear stress to entrain D84 particle size, Tc-84 (lb/ft2)	D84 Particle mobile (yes/no)
1938	2 YR	4.3	0.085	0.0712	5.46	0.3369	0.910	0.073	0.202	38	0.047	0.479	**Yes**
1938	25 YR	15.0	0.085	0.0717	7.8	0.5508	1.560	0.073	0.202	38	0.047	0.479	**Yes**
1938	50 YR	18.3	0.085	0.0709	8.05	0.6137	1.720	0.073	0.202	38	0.047	0.479	**Yes**
1938	100 YR	42.5	0.085	0.0723	8.05	1.0190	3.080	0.073	0.202	38	0.047	0.479	**Yes**

Modified Shields Calculation for Particle Mobility
South Tributary to Friday Creek
Otak, April 2022

Streambed Gravel, Proposed Reach A, Structure 1, S = 6.3%

Streambed Gradation

D_{16} =	**0.05**	*in*	**1.21**	*mm*
D_{50} =	**0.88**	*in*	**22.36**	*mm*
D_{84} =	**2.43**	*in*	**61.60**	*mm*
D_{95} =	**7.41**	*in*	**188.26**	*mm*

Specific Weight of Sediment Particle, γ_s =	165	*pounds per cubic foot*
Specific Weight of Water, γ =	62.4	*pounds per cubic foot*
Shields parameter for D_{50} (τ_{D50}) =	**0.047**	*dimensionless*
Stream Slope=	0.0633	*ft/ft*

Particle Size		Percent Passing (%)	τ_{ci}	Peak Flow *cubic feet per second*				
				2-year	25-year	50-year	100-year	
				6.0	18.6	22.1	24.3	
				Average Modeled Shear Stress *pounds per square foot*				
in	*mm*	-	-	0.91	1.56	1.69	1.72	
8.0	204.0	100	**0.69**	Mobile	Mobile	Mobile	Mobile	
6.0	153.0	97	**0.63**	Mobile	Mobile	Mobile	Mobile	
5.0	127.0	93	**0.60**	Mobile	Mobile	Mobile	Mobile	
4.0	102.0	91	**0.56**	Mobile	Mobile	Mobile	Mobile	
3.0	77.0	88	**0.51**	Mobile	Mobile	Mobile	Mobile	
2.5	64.0	87	**0.48**	Mobile	Mobile	Mobile	Mobile	
2.0	51.0	69	**0.45**	Mobile	Mobile	Mobile	Mobile	
1.5	39.0	63	**0.42**	Mobile	Mobile	Mobile	Mobile	
1.25	32.0		**0.39**	Mobile	Mobile	Mobile	Mobile	
1.00	26.0	57	**0.37**	Mobile	Mobile	Mobile	Mobile	
0.75	20.0	43	**0.34**	Mobile	Mobile	Mobile	Mobile	
0.50	13.0		**0.30**	Mobile	Mobile	Mobile	Mobile	
0.375	10.0		**0.27**	Mobile	Mobile	Mobile	Mobile	
0.187	5.0	28.6	**0.22**	Mobile	Mobile	Mobile	Mobile	
0.017	1.0	13.2	**0.11**	Mobile	Mobile	Mobile	Mobile	
0.003	1.0		**0.06**	Mobile	Mobile	Mobile	Mobile	

Modified Shields Calculation for Particle Mobility
South Tributary to Friday Creek
Otak, April 2022

Streambed Gravel, Proposed Reach A, Structure 2, S = 4.05%

Streambed Gradation

D_{16} =	**0.05**	*in*	**1.21**	*mm*
D_{50} =	**0.88**	*in*	**22.36**	*mm*
D_{84} =	**2.43**	*in*	**61.60**	*mm*
D_{95} =	**7.41**	*in*	**188.26**	*mm*

Specific Weight of Sediment Particle, γ_s =	165	*pounds per cubic foot*
Specific Weight of Water, γ =	62.4	*pounds per cubic foot*
Shields parameter for D_{50} (τ_{D50}) =	**0.047**	*dimensionless*
Stream Slope=	0.0405	*ft/ft*

Particle Size		Percent Passing (%)	τ_{ci}	Peak Flow *cubic feet per second*				
				2-year	**25-year**	**50-year**	**100-year**	
				6.0	18.6	22.1	24.3	
				Average Modeled Shear Stress *pounds per square foot*				
in	*mm*	-	-	0.61	1.03	1.15	1.21	
8.0	204.0	100	**0.69**	Immobile	Mobile	Mobile	Mobile	
6.0	153.0	97	**0.63**	Immobile	Mobile	Mobile	Mobile	
5.0	127.0	93	**0.60**	Mobile	Mobile	Mobile	Mobile	
4.0	102.0	91	**0.56**	Mobile	Mobile	Mobile	Mobile	
3.0	77.0	88	**0.51**	Mobile	Mobile	Mobile	Mobile	
2.5	64.0	87	**0.48**	Mobile	Mobile	Mobile	Mobile	
2.0	51.0	69	**0.45**	Mobile	Mobile	Mobile	Mobile	
1.5	39.0	63	**0.42**	Mobile	Mobile	Mobile	Mobile	
1.25	32.0		**0.39**	Mobile	Mobile	Mobile	Mobile	
1.00	26.0	57	**0.37**	Mobile	Mobile	Mobile	Mobile	
0.75	20.0	43	**0.34**	Mobile	Mobile	Mobile	Mobile	
0.50	13.0		**0.30**	Mobile	Mobile	Mobile	Mobile	
0.375	10.0		**0.27**	Mobile	Mobile	Mobile	Mobile	
0.187	5.0	28.6	**0.22**	Mobile	Mobile	Mobile	Mobile	
0.017	1.0	13.2	**0.11**	Mobile	Mobile	Mobile	Mobile	
0.003	1.0		**0.06**	Mobile	Mobile	Mobile	Mobile	

Modified Shields Calculation for Particle Mobility
South Tributary to Friday Creek
Otak, April 2022

Boulder Steps, Proposed Reach A, Structure 1, S = 6.3%

Streambed Gradation

D_{16} =	**3.50**	*in*	**88.90**	*mm*
D_{50} =	**11.30**	*in*	**287.02**	*mm*
D_{84} =	**28.20**	*in*	**716.28**	*mm*
D_{95} =	**30.00**	*in*	**762.00**	*mm*

Specific Weight of Sediment Particle, γ_s =	165	*pounds per cubic foot*
Specific Weight of Water, γ =	62.4	*pounds per cubic foot*
Shields parameter for D_{50} (τ_{D50}) =	**0.054**	*dimensionless*
Stream Slope=	0.0633	*ft/ft*

Particle Size		**Percent Passing (%)**	τ_{ci}	**Peak Flow** *cubic feet per second*				
				2-year	**25-year**	**50-year**	**100-year**	
				6.0	**18.6**	**22.1**	**24.3**	
				Average Modeled Shear Stress *pounds per square foot*				
in	*mm*	-	-	**0.91**	**1.56**	**1.69**	**1.72**	
30.0	762.0	100	**6.99**	Immobile	Immobile	Immobile	Immobile	
24.0	610.0	76	**6.54**	Immobile	Immobile	Immobile	Immobile	
18.0	458.0	63	**6.00**	Immobile	Immobile	Immobile	Immobile	
12.0	305.0	51	**5.31**	Immobile	Immobile	Immobile	Immobile	
10.0	254.0	44	**5.03**	Immobile	Immobile	Immobile	Immobile	
8.0	204.0	36	**4.70**	Immobile	Immobile	Immobile	Immobile	
6.0	153.0	27	**4.31**	Immobile	Immobile	Immobile	Immobile	
5.0	127.0	23	**4.09**	Immobile	Immobile	Immobile	Immobile	
4.0	102.0	18	**3.82**	Immobile	Immobile	Immobile	Immobile	
3.0	77.0	14	**3.50**	Immobile	Immobile	Immobile	Immobile	
2.5	64.0	12	**3.32**	Immobile	Immobile	Immobile	Immobile	
2.0	51.0	9	**3.10**	Immobile	Immobile	Immobile	Immobile	
1.5	39.0	7	**2.85**	Immobile	Immobile	Immobile	Immobile	
1.25	32.0	6	**2.70**	Immobile	Immobile	Immobile	Immobile	
1.00	26.0	5	**2.52**	Immobile	Immobile	Immobile	Immobile	
0.75	20.0	4	**2.31**	Immobile	Immobile	Immobile	Immobile	
0.50	13.0	3	**2.05**	Immobile	Immobile	Immobile	Immobile	
0.375	10.0	2	**1.88**	Immobile	Immobile	Immobile	Immobile	
0.187	5.0	1	**1.52**	Immobile	Mobile	Mobile	Mobile	
0.017	1.0	1	**0.74**	Mobile	Mobile	Mobile	Mobile	
0.003	1.0	1	**0.44**	Mobile	Mobile	Mobile	Mobile	

Modified Shields Calculation for Particle Mobility
South Tributary to Friday Creek
Otak, April 2022

Boulder Steps, Proposed Reach A, Structure 1, S = 6.3%

Streambed Gradation

D_{16} =	3.50	*in*	88.90	*mm*
D_{50} =	11.30	*in*	287.02	*mm*
D_{84} =	28.20	*in*	716.28	*mm*
D_{95} =	30.00	*in*	762.00	*mm*

Specific Weight of Sediment Particle, γ_s =	165	*pounds per cubic foot*
Specific Weight of Water, γ =	62.4	*pounds per cubic foot*
Shields parameter for D_{50} (τ_{D50}) =	0.054	*dimensionless*
Stream Slope=	0.0633	*ft/ft*

Particle Size		Percent Passing (%)	τ_{ci}	Peak Flow *cubic feet per second*				
				2-year	25-year	50-year	100-year	
				6.0	18.6	22.1	24.3	
				Average Modeled Shear Stress *pounds per square foot*				
in	*mm*	-	-	0.61	1.03	1.15	1.21	
30.0	762.0	100	6.99	Immobile	Immobile	Immobile	Immobile	
24.0	610.0	76	6.54	Immobile	Immobile	Immobile	Immobile	
18.0	458.0	63	6.00	Immobile	Immobile	Immobile	Immobile	
12.0	305.0	51	5.31	Immobile	Immobile	Immobile	Immobile	
10.0	254.0	44	5.03	Immobile	Immobile	Immobile	Immobile	
8.0	204.0	36	4.70	Immobile	Immobile	Immobile	Immobile	
6.0	153.0	27	4.31	Immobile	Immobile	Immobile	Immobile	
5.0	127.0	23	4.09	Immobile	Immobile	Immobile	Immobile	
4.0	102.0	18	3.82	Immobile	Immobile	Immobile	Immobile	
3.0	77.0	14	3.50	Immobile	Immobile	Immobile	Immobile	
2.5	64.0	12	3.32	Immobile	Immobile	Immobile	Immobile	
2.0	51.0	9	3.10	Immobile	Immobile	Immobile	Immobile	
1.5	39.0	7	2.85	Immobile	Immobile	Immobile	Immobile	
1.25	32.0	6	2.70	Immobile	Immobile	Immobile	Immobile	
1.00	26.0	5	2.52	Immobile	Immobile	Immobile	Immobile	
0.75	20.0	4	2.31	Immobile	Immobile	Immobile	Immobile	
0.50	13.0	3	2.05	Immobile	Immobile	Immobile	Immobile	
0.375	10.0	2	1.88	Immobile	Immobile	Immobile	Immobile	
0.187	5.0	1	1.52	Immobile	Immobile	Immobile	Immobile	
0.017	1.0	1	0.74	Immobile	Mobile	Mobile	Mobile	
0.003	1.0	1	0.44	Mobile	Mobile	Mobile	Mobile	

South Tributary to Friday Creek

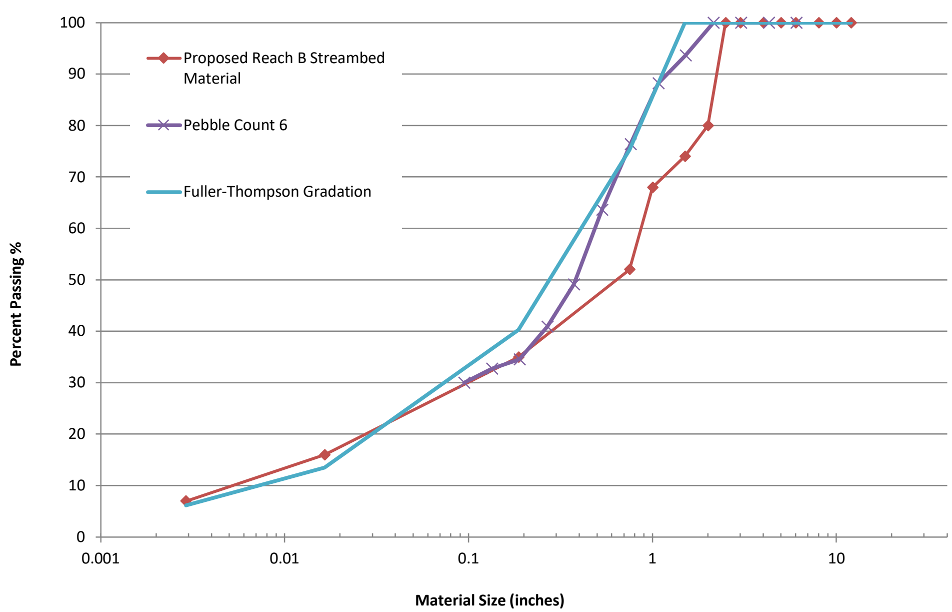
Proposed Reach B Streambed Material

Rock Size				Percent Passing (%)						
MM		Inches	Feet	WSDOT Streambed Sediment	WSDOT 4" Cobbles	WSDOT 6" Cobbles	WSDOT 8" Cobbles	WSDOT 10" Cobbles	WSDOT 12" Cobbles	Design Gradation (%)
304.8		12	1	100	100	100	100	100	100	**100**
254		10	0.83	100	100	100	100	100	83	**100**
203.2		8	0.67	100	100	100	100	83	65	**100**
152.4		6	0.5	100	100	100	83	65	53	**100**
127		5	0.42	100	100	83	65	53	40	**100**
101.6		4	0.33	100	100	65	53	40	35	**100**
76.2		3	0.25	100	84	57	40	34	29	**100**
63.5		2.5	0.21	100	65	48	33	27	24	**100**
50.8		2	0.17	80	51	40	26	21	18	**80**
38.1		1.5	0.13	74	35	30	19	15	13	**74**
25.4		1	0.08	68	23	20	12	8	7	**68**
19.05		0.75	0.06	52	10	10	5	2	2	**52**
4.7498	No.4	0.19		35	7	7	3	1	1	**35**
0.4191	No.40	0.017		16	3	3	2	1	1	**16**
0.07366	No.200	0.0029		7						**7**
		% Per Category		**100**						**100**

Note: 5% Minimum

Design Gradation:			Observed Average Gradation		
	(IN)	(FT)	% Passing	(IN)	(FT)
D100	2.48	0.21	100	1.41	0.12
D84	2.10	0.175	84	0.86	0.071
D50	0.68	0.057	50	0.08	0.007
D16	0.02	0.00	16	0.08	0.01
DMIN	0.003	0.0002	0	0.08	0.0066

Note: 100% Streambed sediment recommended for spawning gravel.



South Tributary to Friday Creek

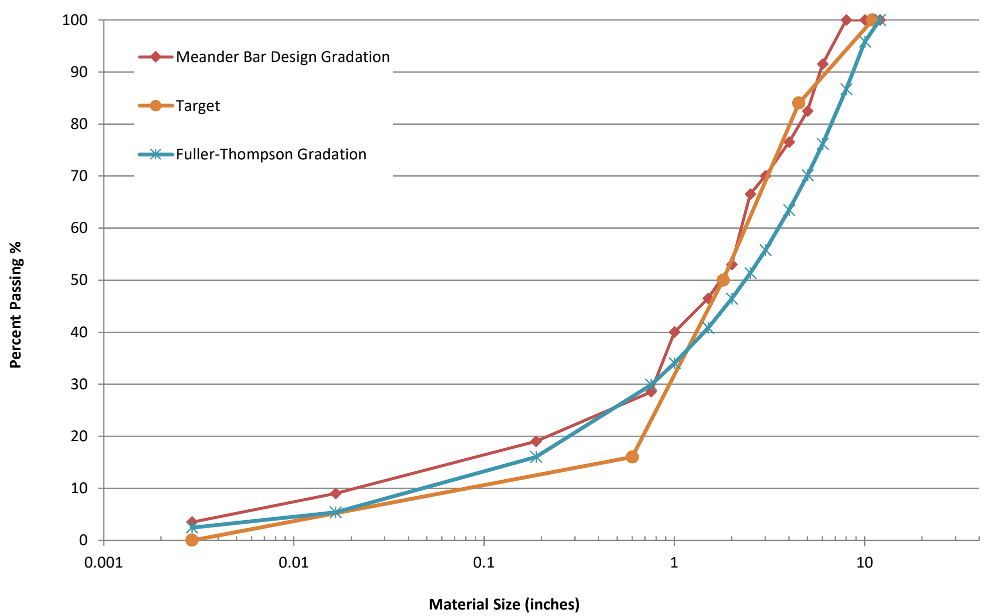
Meander Bar Design Gradation

Rock Size				Percent Passing (%)						
MM		Inches	Feet	WSDOT Streambed Sediment	WSDOT 4" Cobbles	WSDOT 6" Cobbles	WSDOT 8" Cobbles	WSDOT 10" Cobbles	WSDOT 12" Cobbles	Design Gradation (%)
304.8		12	1	100	100	100	100	100	100	**100**
254		10	0.83	100	100	100	100	100	83	**100**
203.2		8	0.67	100	100	100	100	83	65	**100**
152.4		6	0.5	100	100	100	83	65	53	**91.5**
127		5	0.42	100	100	83	65	53	40	**82.5**
101.6		4	0.33	100	100	65	53	40	35	**76.5**
76.2		3	0.25	100	84	57	40	34	29	**70**
63.5		2.5	0.21	100	65	48	33	27	24	**66.5**
50.8		2	0.17	80	51	40	26	21	18	**53**
38.1		1.5	0.13	74	35	30	19	15	13	**46.5**
25.4		1	0.08	68	23	20	12	8	7	**40**
19.05		0.75	0.06	52	10	10	5	2	2	**28.5**
4.7498	No.4	0.19		35	7	7	3	1	1	**19**
0.4191	No.40	0.017		16	3	3	2	1	1	**9**
0.07366	No.200	0.0029		7						**3.5**
			% Per Category	**50**			**50**			**100**

Note: 5% Minimum

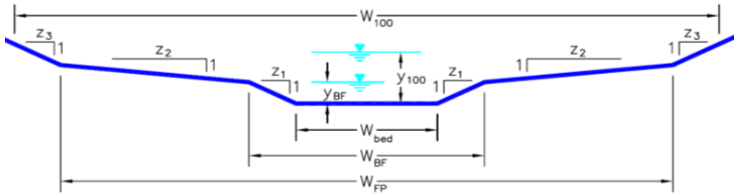
	Design Gradation:		**Target Gradation**		
	(IN)	(FT)	% Passing	(IN)	(FT)
D100	7.76	0.65	100	11.00	0.75
D84	5.17	0.431	84	4.50	0.300
D50	1.77	0.147	50	1.80	0.117
D16	0.14	0.01	16	0.60	0.04
DMIN	0.003	0.0002	0	0.00	0.0002

Design D50 / Target D50 = 0.98



South Tributary to Friday Creek

Meander Bar Stability Calculation



Design Equations (Reference: USDA, NRCS, 2007. NEH part 654: Stream Restoration Design Guide)

[1] Hydraulic Radius: $R = A / P$

[2] Mannings Roughness Coefficient:

Limerinos ($R/D_{84} \geq 4$) $n = (0.0926 * R^{1/6}) / (1.16 + 2 \log (R/D_{84}))$

Mussetter ($R/D_{84} < 4$) $n = (1.486 * R^{1/6}) / (SQRT(g) * 1.11 * (R/D_{84})^{0.46} * (D_{84}/D_{50})^{-0.85} * S^{-0.39})$

[3] Discharge: $Q = (1.486 / n) * A * R^{2/3} * S^{1/2}$

[4] Velocity: $V = Q / A$

[5] Froude Number: $Fr = V / SQRT(g * y)$

[6] Shear Stress: $\tau = \gamma * R * S$

[7] Dimensionless Particle Size: $D_* = D_{50} (1.65g / v^2)^{1/3}$

[8] Critical Dimen. Shields Stress: $\theta_c = (0.24/D_*) + 0.055 [1 - \exp(-0.02D_*)]$

[9] Dimensionless Shear Stress: $\theta = (R*S) / (S_g*D_{50})$

[10] Minimum required D_{50}: Shields Method: $D_{50} = (R * S) / (1.65\ \theta_c)$

Channel Geometry Design and Target Substrate

Channel Design Parameters	Symbol	Units	Value	Notes
Width - Channel Bed	W_{bed}	ft	5.00	
Width - Bankfull	W_{BF}	ft	8.40	
Width - Floodplain	W_{FP}	ft	28.00	
(H:1) - Channel Bank Slope	z_1	__ ft : 1 ft	2.00	
(H:1) - Floodplain Slope	z_2	__ ft : 1 ft	50.00	
(H:1) - High Bank Slope	z_3	__ ft : 1 ft	3.00	
Design Gradient of Channel	S	ft/ft	0.0170	
Design Median Grain Size	D_{50}	ft	0.15	
Design 84th Percentile Grain Size	D_{84}	ft	0.38	WDFW Guidance: D84=2.5*D50 (Equation 3.7 in 2013 Water Crossing Design Guidelines)

Channel Hydraulic Analysis

Channel Hydraulic Parameters	Symbol	Units	2-YR Flow	100-YR Flow	Notes
Depth	y	ft	0.40	0.83	
Wetted Perimeter	P	ft	7.60	9.29	
Area	A	ft^2	3.00	7.45	
Hydraulic Radius	R	ft	0.39	0.80	[Eq. 1]
Relative Submergence	R/D_{84}	-	1.05	2.14	
Manning's Roughness Coefficient	n	-	0.050	0.050	
Calculated Discharge	Q	cfs	6.3	24.9	[Eq. 3]
Calculated Velocity	V	ft/s	2.09	3.34	[Eq. 4]
Froude Number (Fr < 1, subcritical)	Fr	-	0.58	0.65	[Eq. 5]
Shear Stress	τ	lb/ft^2	0.42	0.85	[Eq. 6]
Dimensionless Particle Size	D_*	-	966.2	966.2	[Eq. 7]
Critical Dimensionless Shields Stress	θ_c	-	0.055	0.055	[Eq. 8]
Dimensionless Shear Stress	θ	-	0.027	0.055	[Eq. 9]
Target Median Grain Size	$D_{50,min}$	ft	0.07	0.15	[Eq. 10]

Channel Geometry Design Summary

Design Parameters	Symbol	Units	Value	Notes
Bed Width	W_{bed}	ft	5.00	
Top Width - Bankfull	W_{BF}	ft	8.40	
Top Width - Floodplain	W_{FP}	ft	28.00	
Flow Depth - Q2	y_2	ft	0.40	
Flow Depth - Q_{100}	y_{100}	ft	0.83	
Minimum Grain Size	D_{min}	in	sand	Need 5% to 10% fines
16th Percentile Grain Size	D_{16}	in	0.6	$D_{16} = D_{84} / 8$
Median Grain Size	D_{50}	in	1.8	
84th Percentile Grain Size	D_{84}	in	4.5	$D_{84} = (2.5) * D_{50}$
Maximum Grain Size	D_{max}	in	11.0	$D_{max} = D_{84} / 0.4$

Modified Shields Calculation for Streambed Mobility
South Tributary - Proposed Reach B (< 4 % slope)
Otak, April 2022

Table A.3. Existing Conditions Downstream Reach

		Hydraulics						Particle Mobility / Stability					
Cross Section	**Recurrence Interval**	**Discharge, Q (ft3/s)**	**Channel n value**	**Energy Slope Se**	**Channel Flow Width, Wc (ft**	**Channel Hydraulic Radius, Rc (ft)**	**Channel boundary shear stress Tc (lb/ft2)**	**D50 (feet)**	**D84 (feet)**	**Angle of repose**	**Shield's entrainment for D50, T50**	**Critical Shear stress to entrain D84 particle size, Tc-84 (lb/ft2)**	**D84 Particle mobile (yes/no)**
1631	2 YR	1.43	0.045	0.0169	2.48	0.5521	0.581	0.038	0.097	36	0.044	0.227	**Yes**
1631	25 YR	22.4	0.045	0.0120	6.21	0.9817	0.733	0.038	0.097	36	0.044	0.227	**Yes**
1631	50 YR	23.19	0.045	0.0115	6.26	0.9974	0.719	0.038	0.097	36	0.044	0.227	**Yes**
1631	100 YR	23.92	0.045	0.0117	7.15	0.9372	0.681	0.038	0.097	36	0.044	0.227	**Yes**

Table A.4. Proposed Conditions Reach B - Structure 3

		Hydraulics						Particle Mobility / Stability					
Cross Section	**Recurrence Interval**	**Discharge, Q (ft3/s)**	**Channel n value**	**Energy Slope Se**	**Channel Flow Width, Wc (ft**	**Channel Hydraulic Radius, Rc (ft)**	**Channel boundary shear stress Tc (lb/ft2)**	**D50 (feet)**	**D84 (feet)**	**Angle of repose**	**Shield's entrainment for D50, T50**	**Critical Shear stress to entrain D84 particle size, Tc-84 (lb/ft2)**	**D84 Particle mobile (yes/no)**
1437	2 YR	6.2	0.060	0.0187	7.44	0.4323	0.370	0.057	0.175	36	0.044	0.360	**Yes**
1437	25 YR	19.1	0.060	0.0183	9	0.6868	0.650	0.057	0.175	36	0.044	0.360	**Yes**
1437	50 YR	24.2	0.060	0.0181	9	0.8019	0.720	0.057	0.175	36	0.044	0.360	**Yes**
1437	100 YR	46.7	0.060	0.0177	9	1.1873	1.050	0.057	0.175	36	0.044	0.360	**Yes**

Modified Shields Calculation for Particle Mobility
South Tributary to Friday Creek
Otak, April 2022

Streambed Gravel, Proposed Reach B, S = 2.6%

Streambed Gradation

D_{16} =	**0.05**	*in*	**1.21**	*mm*
D_{50} =	**0.88**	*in*	**22.36**	*mm*
D_{84} =	**2.43**	*in*	**61.60**	*mm*
D_{95} =	**7.41**	*in*	**188.26**	*mm*

Specific Weight of Sediment Particle, γ_s =	165	*pounds per cubic foot*
Specific Weight of Water, γ =	62.4	*pounds per cubic foot*
Shields parameter for D_{50} (τ_{D50}) =	**0.047**	*dimensionless*
Stream Slope=	0.0259	*ft/ft*

Particle Size		Percent Passing (%)	τ_{ci}	Peak Flow *cubic feet per second*				
				2-year	**25-year**	**50-year**	**100-year**	
				6.0	18.6	22.1	24.3	
				Average Modeled Shear Stress *pounds per square foot*				
in	*mm*	-	-	0.56	1.02	1.03	1.04	
8.0	204.0	100	**0.69**	Immobile	Mobile	Mobile	Mobile	
6.0	153.0	97	**0.63**	Immobile	Mobile	Mobile	Mobile	
5.0	127.0	93	**0.60**	Immobile	Mobile	Mobile	Mobile	
4.0	102.0	91	**0.56**	Mobile	Mobile	Mobile	Mobile	
3.0	77.0	88	**0.51**	Mobile	Mobile	Mobile	Mobile	
2.5	64.0	87	**0.48**	Mobile	Mobile	Mobile	Mobile	
2.0	51.0	69	**0.45**	Mobile	Mobile	Mobile	Mobile	
1.5	39.0	63	**0.42**	Mobile	Mobile	Mobile	Mobile	
1.25	32.0		**0.39**	Mobile	Mobile	Mobile	Mobile	
1.00	26.0	57	**0.37**	Mobile	Mobile	Mobile	Mobile	
0.75	20.0	43	**0.34**	Mobile	Mobile	Mobile	Mobile	
0.50	13.0		**0.30**	Mobile	Mobile	Mobile	Mobile	
0.375	10.0		**0.27**	Mobile	Mobile	Mobile	Mobile	
0.187	5.0	28.6	**0.22**	Mobile	Mobile	Mobile	Mobile	
0.017	1.0	13.2	**0.11**	Mobile	Mobile	Mobile	Mobile	
0.003	1.0		**0.06**	Mobile	Mobile	Mobile	Mobile	

Modified Shields Calculation for Particle Mobility
South Tributary to Friday Creek
Otak, April 2022

Proposed Reach B, Structure 3, S = 1.7%

Streambed Gradation

D_{16} =	**0.05**	*in*	**1.21**	*mm*
D_{50} =	**0.88**	*in*	**22.36**	*mm*
D_{84} =	**2.43**	*in*	**61.60**	*mm*
D_{95} =	**7.41**	*in*	**188.26**	*mm*

Specific Weight of Sediment Particle, γ_s =	165	*pounds per cubic foot*
Specific Weight of Water, γ =	62.4	*pounds per cubic foot*
Shields parameter for D_{50} (τ_{D50}) =	**0.047**	*dimensionless*
Stream Slope=	0.0166	*ft/ft*

Particle Size		**Percent Passing (%)**	τ_{ci}	**Peak Flow** *cubic feet per second*				
				2-year	**25-year**	**50-year**	**100-year**	
				6.0	**18.6**	**22.1**	**24.3**	
				Average Modeled Shear Stress *pounds per square foot*				
in	*mm*	-	-	**0.37**	**0.65**	**0.68**	**0.72**	
8.0	204.0	100	**0.69**	Immobile	Immobile	Immobile	Mobile	
6.0	153.0	97	**0.63**	Immobile	Mobile	Mobile	Mobile	
5.0	127.0	93	**0.60**	Immobile	Mobile	Mobile	Mobile	
4.0	102.0	91	**0.56**	Immobile	Mobile	Mobile	Mobile	
3.0	77.0	88	**0.51**	Immobile	Mobile	Mobile	Mobile	
2.5	64.0	87	**0.48**	Immobile	Mobile	Mobile	Mobile	
2.0	51.0	69	**0.45**	Immobile	Mobile	Mobile	Mobile	
1.5	39.0	63	**0.42**	Immobile	Mobile	Mobile	Mobile	
1.25	32.0		**0.39**	Immobile	Mobile	Mobile	Mobile	
1.00	26.0	57	**0.37**	Mobile	Mobile	Mobile	Mobile	
0.75	20.0	43	**0.34**	Mobile	Mobile	Mobile	Mobile	
0.50	13.0		**0.30**	Mobile	Mobile	Mobile	Mobile	
0.375	10.0		**0.27**	Mobile	Mobile	Mobile	Mobile	
0.187	5.0	28.6	**0.22**	Mobile	Mobile	Mobile	Mobile	
0.017	1.0	13.2	**0.11**	Mobile	Mobile	Mobile	Mobile	
0.003	1.0		**0.06**	Mobile	Mobile	Mobile	Mobile	

Modified Shields Calculation for Particle Mobility
South Tributary to Friday Creek
Otak, April 2022

Meander Bars, Proposed Reach B, Structure 3, S = 1.7%

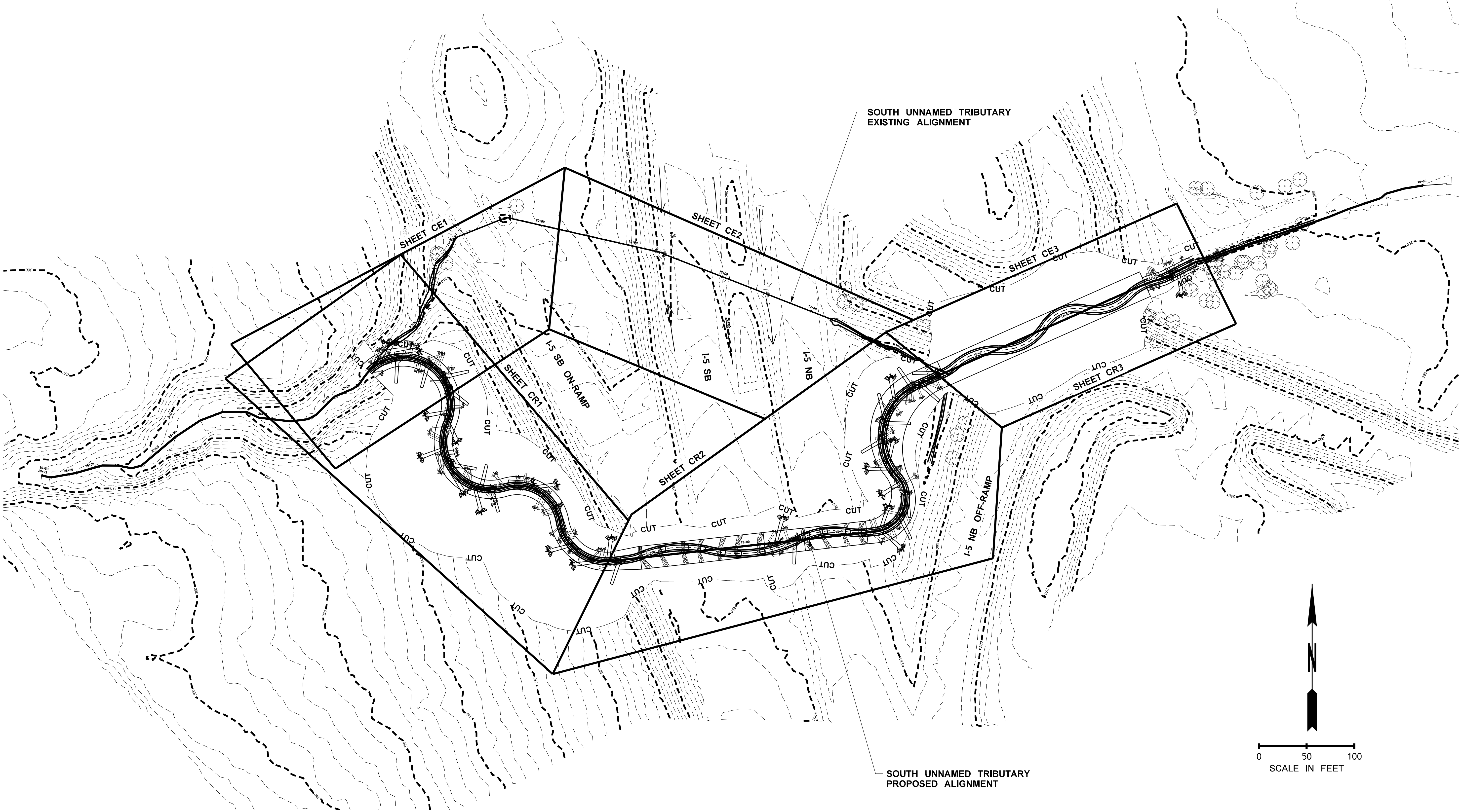
Streambed Gradation

D_{16} =	**0.60**	*in*	**15.24**	*mm*
D_{50} =	**1.80**	*in*	**45.72**	*mm*
D_{84} =	**4.50**	*in*	**114.30**	*mm*
D_{95} =	**11.00**	*in*	**279.40**	*mm*

Specific Weight of Sediment Particle, γ_s =	**165**	*pounds per cubic foot*
Specific Weight of Water, γ =	**62.4**	*pounds per cubic foot*
Shields parameter for D_{50} (τ_{D50}) =	**0.050**	*dimensionless*
Stream Slope=	0.0166	*ft/ft*

Particle Size		Percent Passing (%)	τ_{ci}	Peak Flow *cubic feet per second*				
				2-year	**25-year**	**50-year**	**100-year**	
				6.0	**18.6**	**22.1**	**24.3**	
				Average Modeled Shear Stress *pounds per square foot*				
in	*mm*	-	-	**0.37**	**0.65**	**0.68**	**0.72**	
6.0	153.0	100	**1.10**	Immobile	Immobile	Immobile	Immobile	
5.0	127.0	85	**1.05**	Immobile	Immobile	Immobile	Immobile	
4.0	102.0	78	**0.98**	Immobile	Immobile	Immobile	Immobile	
3.0	77.0	65	**0.90**	Immobile	Immobile	Immobile	Immobile	
2.5	64.0	59	**0.85**	Immobile	Immobile	Immobile	Immobile	
2.0	51.0	53	**0.79**	Immobile	Immobile	Immobile	Immobile	
1.5	39.0	46	**0.73**	Immobile	Immobile	Immobile	Immobile	
1.25	32.0	34	**0.69**	Immobile	Immobile	Immobile	Mobile	
1.00	26.0	27	**0.65**	Immobile	Mobile	Mobile	Mobile	
0.75	20.0	20	**0.59**	Immobile	Mobile	Mobile	Mobile	
0.50	13.0	13	**0.52**	Immobile	Mobile	Mobile	Mobile	
0.375	10.0	10	**0.48**	Immobile	Mobile	Mobile	Mobile	
0.187	5.0	4	**0.39**	Immobile	Mobile	Mobile	Mobile	
0.017	1.0	0	**0.19**	Mobile	Mobile	Mobile	Mobile	
0.003	1.0	0	**0.11**	Mobile	Mobile	Mobile	Mobile	

Appendix E: Stream Plan Sheets, Profile, and Details



FILE NAME	K:\Project\33100\33178B\CADD\MicroStation\995236\EngDataDesign\Geometry\Full Site Sheet Layout-995239.dgn				
TIME	5:15:50 PM				
DATE	4/20/2022				
PLOTTED BY	Teddy.Thorson				
DESIGNED BY	D. STEWART				
ENTERED BY	J. WILKES				
CHECKED BY	N. POSEY				
PROJ. ENGR.					
REGIONAL ADM.		REVISION	DATE	BY	

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

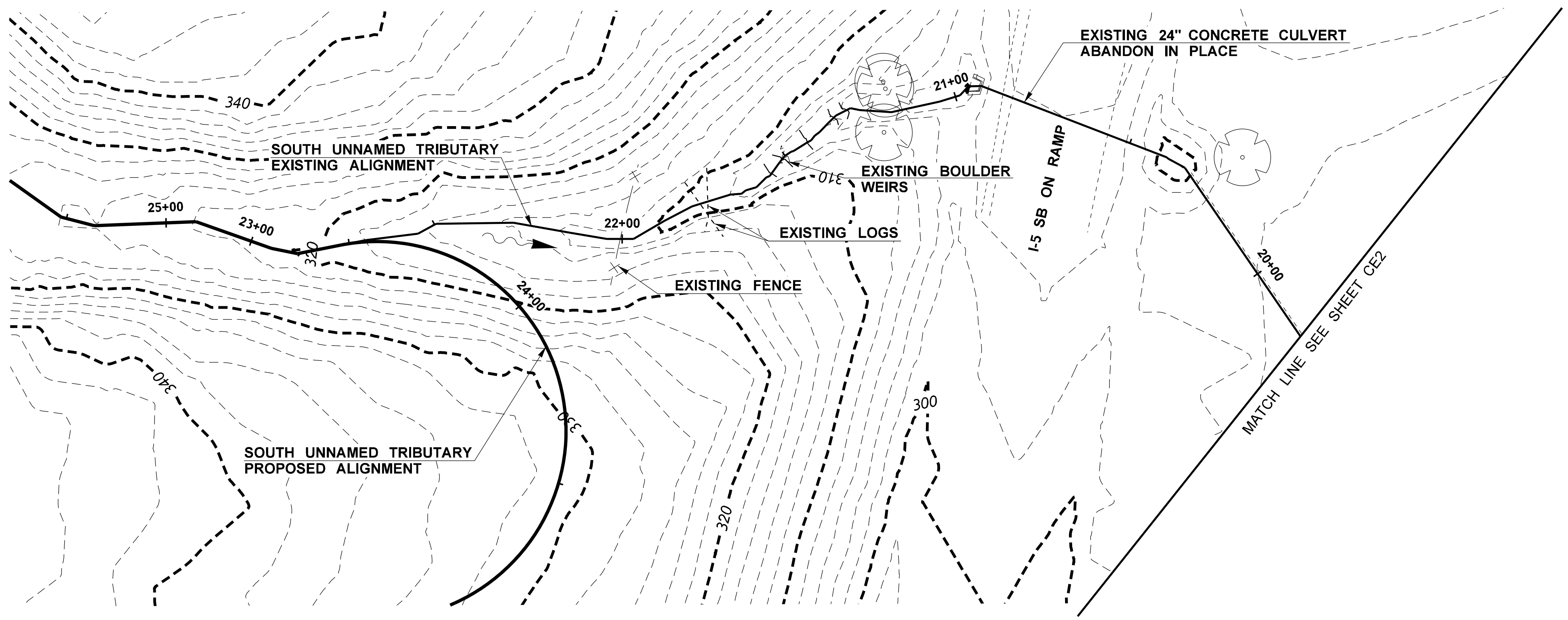
Washington State
Department of Transportation

I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY
TO FRIDAY CREEK

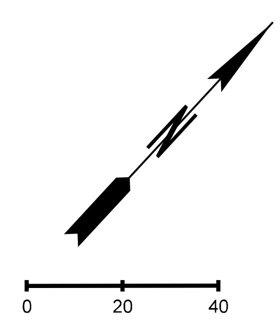
STREAM PLAN SITE KEY

PLAN REF NO
CK1

SHEET
1
OF
13
SHEETS



PRELIMINARY - NOT FOR CONSTRUCTION



LEGEND

260	EXISTING INDEX CONTOUR		EXISTING TREE
	EXISTING INTERMEDIATE CONTOUR		EXISTING LOGS
	EXISTING EDGE OF PAVEMENT	10+00	EXISTING STREAM ALIGNMENT
	EXISTING FENCE	10+00	PROPOSED STREAM ALIGNMENT
	EXISTING BOULDER WEIR		

NOTES:

1. HORIZONTAL DATUM: WASHINGTON STATE PLANE NORTH, NAD83/11
2. VERTICAL DATUM: NAVD 88
3. SURVEY PERFORMED BY OTAK IN DECEMBER 2020, 2016 LIDAR PROVIDED BY WSDOT

FILE NAME	$FILE$
TIME	1:32:08 PM
DATE	4/25/2022
PLOTTED BY	Teddy.Thorson
DESIGNED BY	D. STEWART
ENTERED BY	J. WILKES
CHECKED BY	N. POSEY
PROJ. ENGR.	
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

DATE
P.E. STAMP BOX

DATE
P.E. STAMP BOX

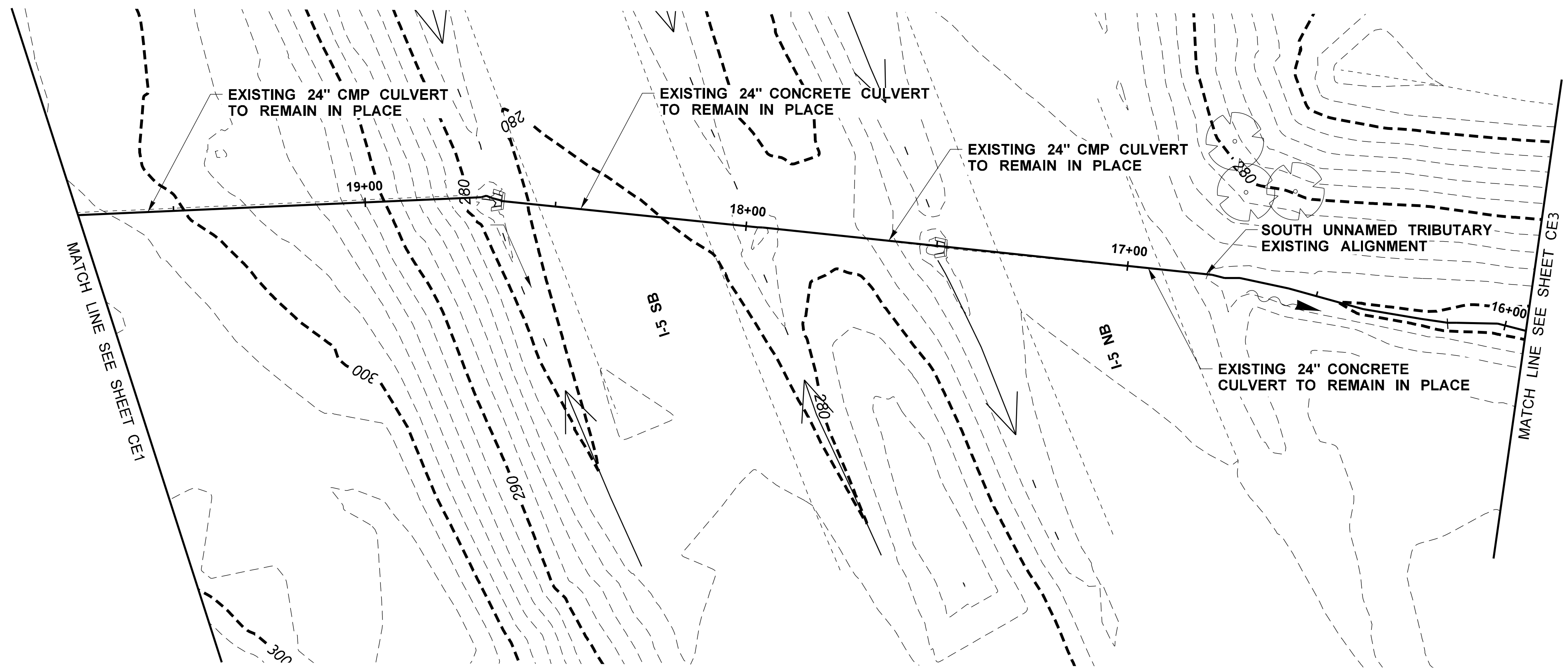
Washington State
Department of Transportation

I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY
TO FRIDAY CREEK

EXISTING STREAM PLAN

PLAN REF NO
CE1

SHEET
2
OF
13
SHEETS



PRELIMINARY - NOT FOR CONSTRUCTION

LEGEND

260	EXISTING INDEX CONTOUR		EXISTING TREE
	EXISTING INTERMEDIATE CONTOUR		EXISTING LOGS
	EXISTING EDGE OF PAVEMENT	10+00	EXISTING STREAM ALIGNMENT
	EXISTING FENCE	10+00	PROPOSED STREAM ALIGNMENT
	EXISTING BOULDER WEIR		

NOTES:

1. HORIZONTAL DATUM: WASHINGTON STATE PLANE NORTH, NAD83/11
2. VERTICAL DATUM: NAVD 88
3. SURVEY PERFORMED BY OTAK IN DECEMBER 2020, 2016 LIDAR PROVIDED BY WSDOT

FILE NAME	$FILE$
TIME	1:29:34 PM
DATE	4/25/2022
PLOTTED BY	Teddy.Thorson
DESIGNED BY	D. STEWART
ENTERED BY	J. WILKES
CHECKED BY	N. POSEY
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

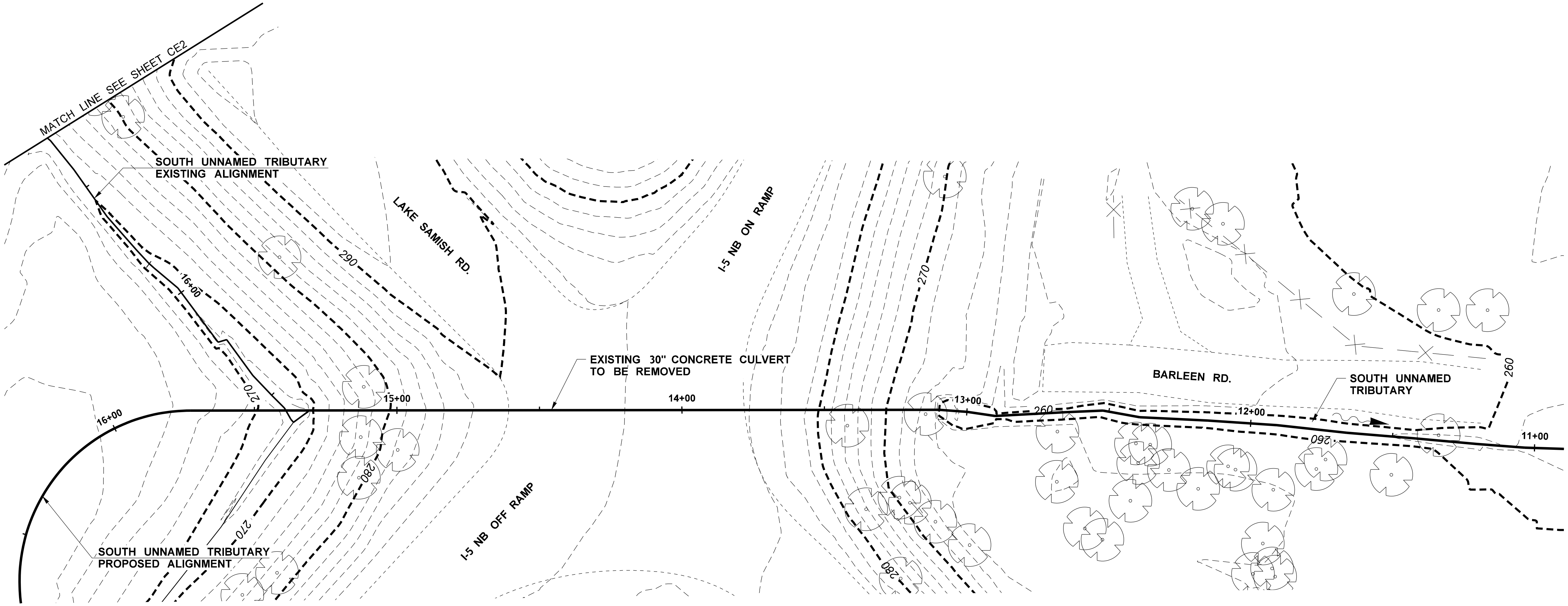
Washington State Department of Transportation

I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY TO FRIDAY CREEK

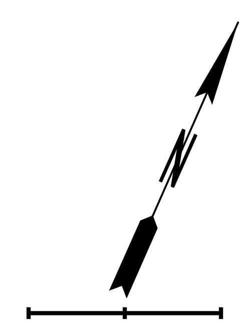
EXISTING STREAM PLAN

PLAN REF NO CE2

SHEET 3 OF 13 SHEETS



PRELIMINARY - NOT FOR CONSTRUCTION



LEGEND

260	EXISTING INDEX CONTOUR		EXISTING TREE
	EXISTING INTERMEDIATE CONTOUR		EXISTING LOGS
	EXISTING EDGE OF PAVEMENT	10+00	EXISTING STREAM ALIGNMENT
	EXISTING FENCE	10+00	PROPOSED STREAM ALIGNMENT
	EXISTING BOULDER WEIR		

NOTES:

1. HORIZONTAL DATUM: WASHINGTON STATE PLANE NORTH, NAD83/11
2. VERTICAL DATUM: NAVD 88
3. SURVEY PERFORMED BY OTAK IN DECEMBER 2020, 2016 LIDAR PROVIDED BY WSDOT

FILE NAME	$FILE$
TIME	1:27:34 PM
DATE	4/25/2022
PLOTTED BY	Teddy.Thorson
DESIGNED BY	D. STEWART
ENTERED BY	J. WILKES
CHECKED BY	N. POSEY
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	

JOB NUMBER

CONTRACT NO. | LOCATION NO.

DATE
P.E. STAMP BOX

DATE
P.E. STAMP BOX

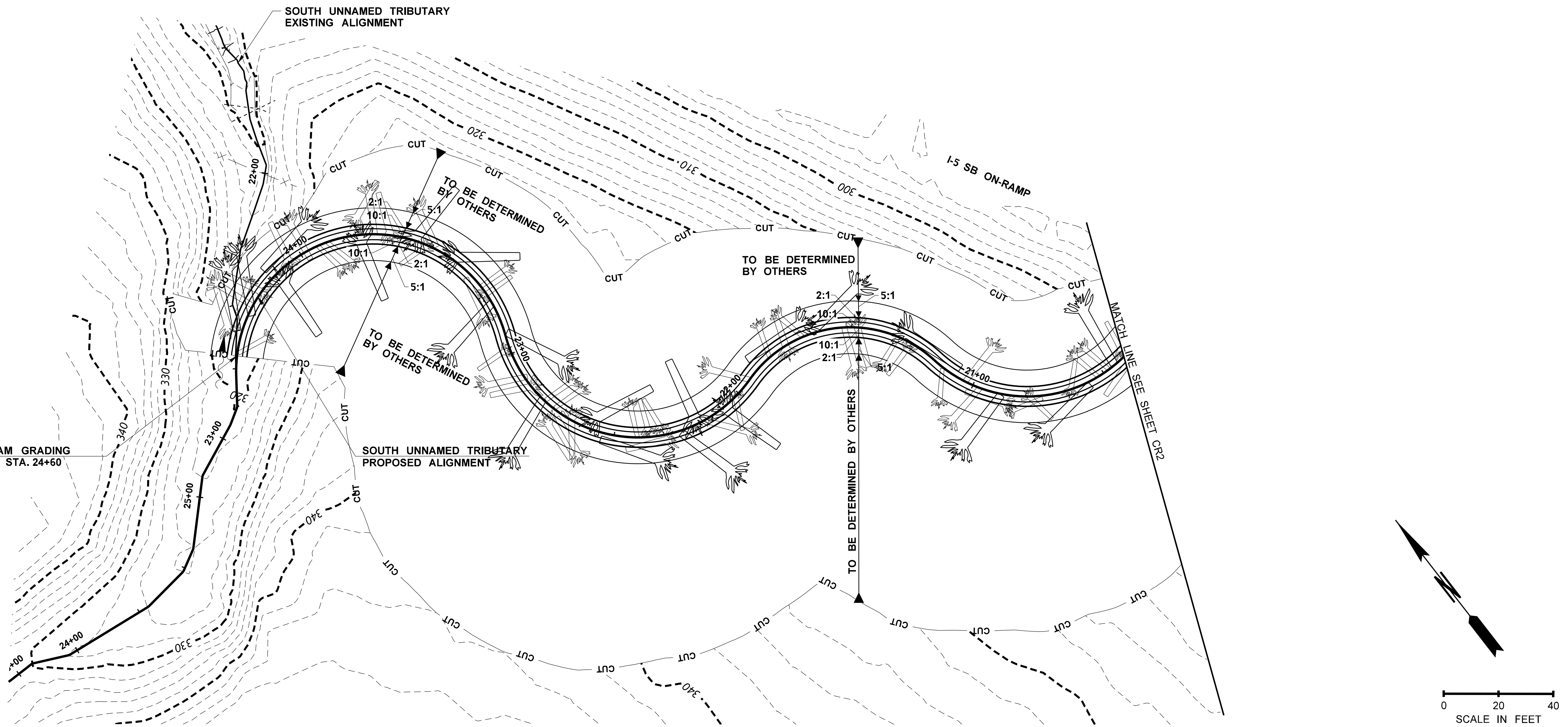
Washington State
Department of Transportation

I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY
TO FRIDAY CREEK

EXISTING STREAM PLAN

PLAN REF NO
CE3

SHEET
4
OF
13
SHEETS



PRELIMINARY - NOT FOR CONSTRUCTION

NOTES:

1. EXACT STRUCTURE TYPE, SIZE, LOCATION AND WALLS TO BE DETERMINED.
2. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL LIMITS TO BE BASED ON FINAL STRUCTURE, TYPE, SIZE AND LOCATION.
3. LOCATION AND ORIENTATION OF LARGE WOODY MATERIAL (LWM) STRUCTURES AS SHOWN ON THIS SHEET ARE APPROXIMATE AND WILL BE STAKED BY THE ENGINEER.
4. STREAM ALIGNMENT SHALL BE FURTHER EXAMINED DURING FHD TO MINIMIZE IMPACT TO EXISTING TREES WHERE FEASIBLE.

LEGEND

260	EXISTING INDEX CONTOUR	10+00	EXISTING STREAM ALIGNMENT		LARGE WOODY MATERIAL TYPE A
	EXISTING INTERMEDIATE CONTOUR	10+00	NEW STREAM ALIGNMENT		LARGE WOODY MATERIAL TYPE B
	EXISTING EDGE OF PAVEMENT	CUT	LIMITS OF EXCAVATION		LARGE WOODY MATERIAL TYPE C
	EXISTING FENCE		NEW STRUCTURE		
	EXISTING TREE				

FILE NAME	$FILE$
TIME	1:10:44 PM
DATE	1/6/2023
PLOTTED BY	Teddy.Thorson
DESIGNED BY	D. STEWART
ENTERED BY	J. WILKES
CHECKED BY	N. POSEY
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

DATE
P.E. STAMP BOX

DATE
P.E. STAMP BOX

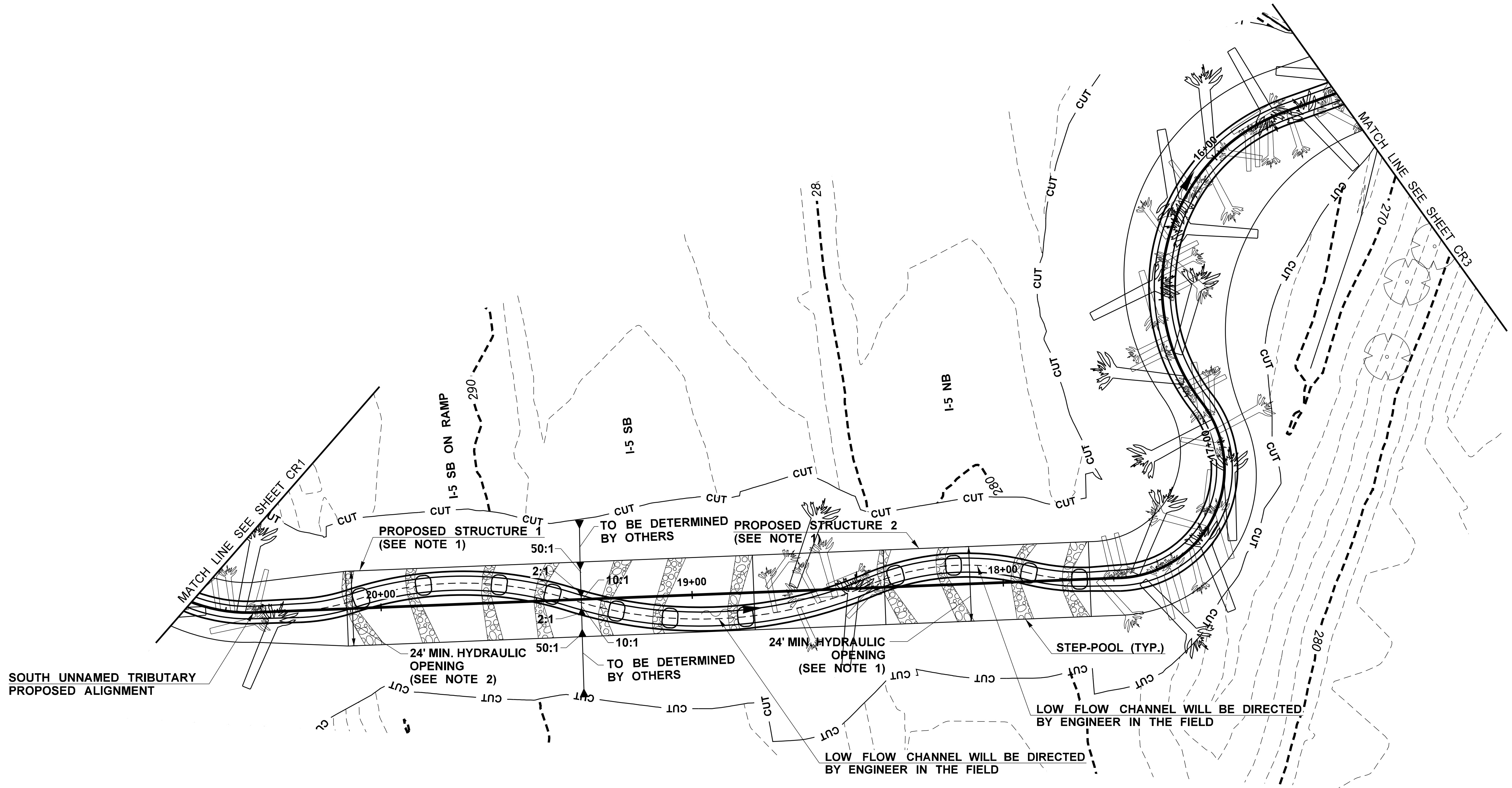
Washington State
Department of Transportation

I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY
TO FRIDAY CREEK

PROPOSED STREAM PLAN

PLAN REF NO
CR1

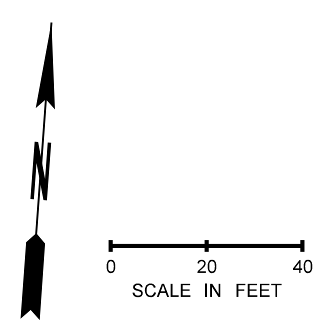
SHEET
5
OF
13
SHEETS



PRELIMINARY - NOT FOR CONSTRUCTION

NOTES:

1. EXACT STRUCTURE TYPE, SIZE, LOCATION AND WALLS TO BE DETERMINED.
2. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL LIMITS TO BE BASED ON FINAL STRUCTURE, TYPE, SIZE AND LOCATION.
3. LOCATION AND ORIENTATION OF LARGE WOODY MATERIAL (LWM) STRUCTURES AS SHOWN ON THIS SHEET ARE APPROXIMATE AND WILL BE STAKED BY THE ENGINEER.
4. STREAM ALIGNMENT SHALL BE FURTHER EXAMINED DURING FHD TO MINIMIZE IMPACT TO EXISTING TREES WHERE FEASIBLE.



LEGEND

- - 260 - -	EXISTING INDEX CONTOUR
	EXISTING INTERMEDIATE CONTOUR
	EXISTING EDGE OF PAVEMENT
	EXISTING FENCE
	EXISTING TREE
10+00	EXISTING STREAM ALIGNMENT
10+00	NEW STREAM ALIGNMENT
- CUT -	LIMITS OF EXCAVATION
	NEW STRUCTURE
	LARGE WOODY MATERIAL TYPE A
	LARGE WOODY MATERIAL TYPE B
	LARGE WOODY MATERIAL TYPE C

FILE NAME	$FILE$
TIME	3:32:02 PM
DATE	1/10/2023
PLOTTED BY	Teddy.Thorson
DESIGNED BY	D. STEWART
ENTERED BY	J. WILKES
CHECKED BY	N. POSEY
PROJ. ENGR.	
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

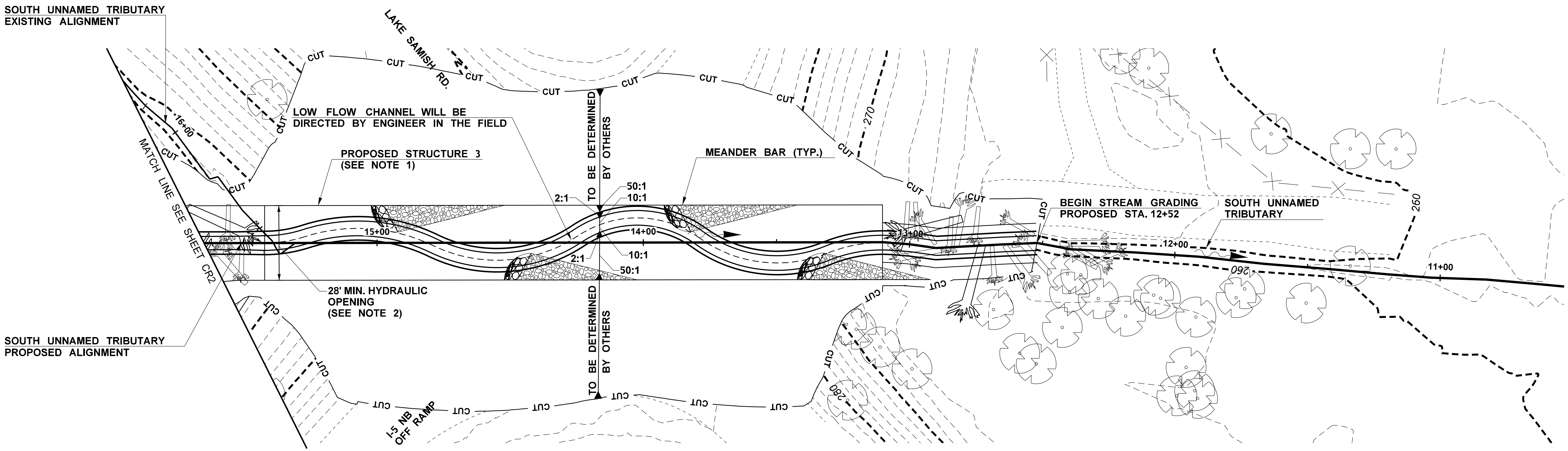
Washington State Department of Transportation

I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY TO FRIDAY CREEK

PROPOSED STREAM PLAN

PLAN REF NO CR2

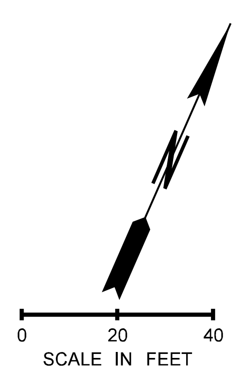
SHEET 6 OF 13 SHEETS



PRELIMINARY - NOT FOR CONSTRUCTION

NOTES:

1. EXACT STRUCTURE TYPE, SIZE, LOCATION AND WALLS TO BE DETERMINED.
2. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL LIMITS TO BE BASED ON FINAL STRUCTURE, TYPE, SIZE AND LOCATION.
3. LOCATION AND ORIENTATION OF LARGE WOODY MATERIAL (LWM) STRUCTURES AS SHOWN ON THIS SHEET ARE APPROXIMATE AND WILL BE STAKED BY THE ENGINEER.
4. STREAM ALIGNMENT SHALL BE FURTHER EXAMINED DURING FHD TO MINIMIZE IMPACT TO EXISTING TREES WHERE FEASIBLE.



LEGEND

260	EXISTING INDEX CONTOUR	10+00	EXISTING STREAM ALIGNMENT		LARGE WOODY MATERIAL TYPE A
	EXISTING INTERMEDIATE CONTOUR	10+00	NEW STREAM ALIGNMENT		LARGE WOODY MATERIAL TYPE B
	EXISTING EDGE OF PAVEMENT	CUT	LIMITS OF EXCAVATION		LARGE WOODY MATERIAL TYPE C
	EXISTING FENCE		NEW STRUCTURE		
	EXISTING TREE				

FILE NAME	$FILE$
TIME	3:24:59 PM
DATE	1/10/2023
PLOTTED BY	Teddy.Thorson
DESIGNED BY	D. STEWART
ENTERED BY	J. WILKES
CHECKED BY	N. POSEY
PROJ. ENGR.	
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

DATE
P.E. STAMP BOX

DATE
P.E. STAMP BOX

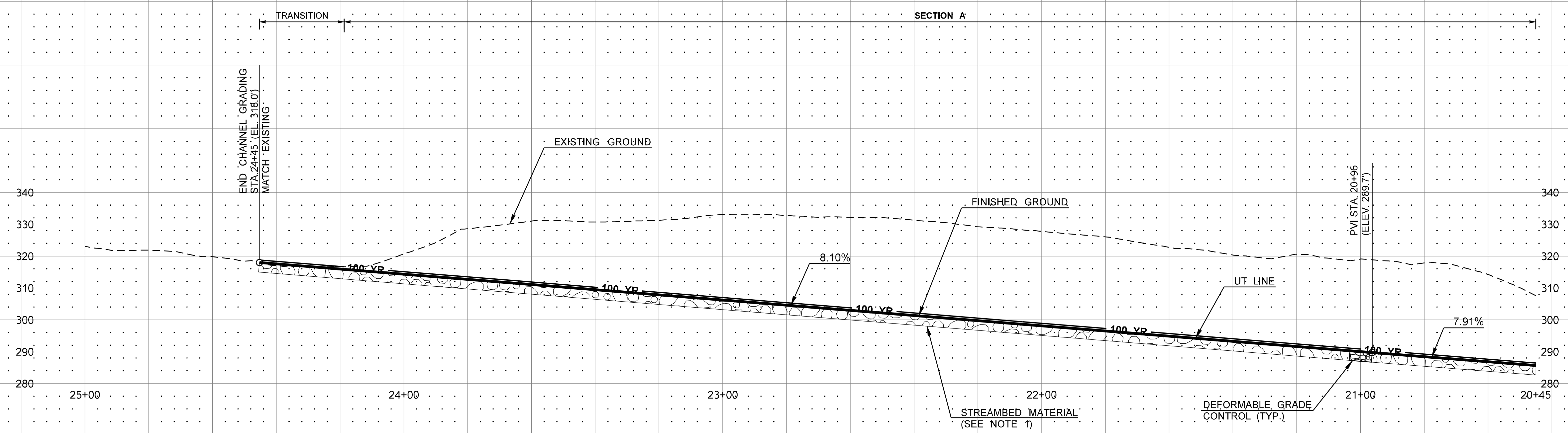
Washington State
Department of Transportation

I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY
TO FRIDAY CREEK

PROPOSED STREAM PLAN

PLAN REF NO
CR3

SHEET
7
OF
13
SHEETS



UT LINE PROFILE

END CHANNEL GRADING STA.24+45

8 IN. STREAMBED COBBLES = X TONS

STREAMBED SEDIMENT = X TONS

CHANNEL EXCAVATION INCL. HAUL = X CY

LWM TYPE A = 22

LWM TYPE B = 25

LWM TYPE C = 25

MATCH LINE STA.20+45

NOTES:

1. SEE SPECIAL PROVISION "AGGREGRATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND COARSE BANDS. FINAL INSTALLATION WILL PROVIDE A WELL GRADED MIX OF STREAMBED SEDIMENTS AND STREAMBED COBBLES.
2. FOR STRUCTURE DETAILS SEE SHEETS 12-13.
3. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
4. EXACT STRUCTURE TYPE, SIZE, LOCATION AND WALLS TO BE DETERMINED.

DATUM (NAVD) 88

PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	$FILE$
TIME	4:37:31 PM
DATE	6/16/2022
PLOTTED BY	Teddy.Thorson
DESIGNED BY	D. STEWART
ENTERED BY	J. WILKES
CHECKED BY	N. POSEY
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

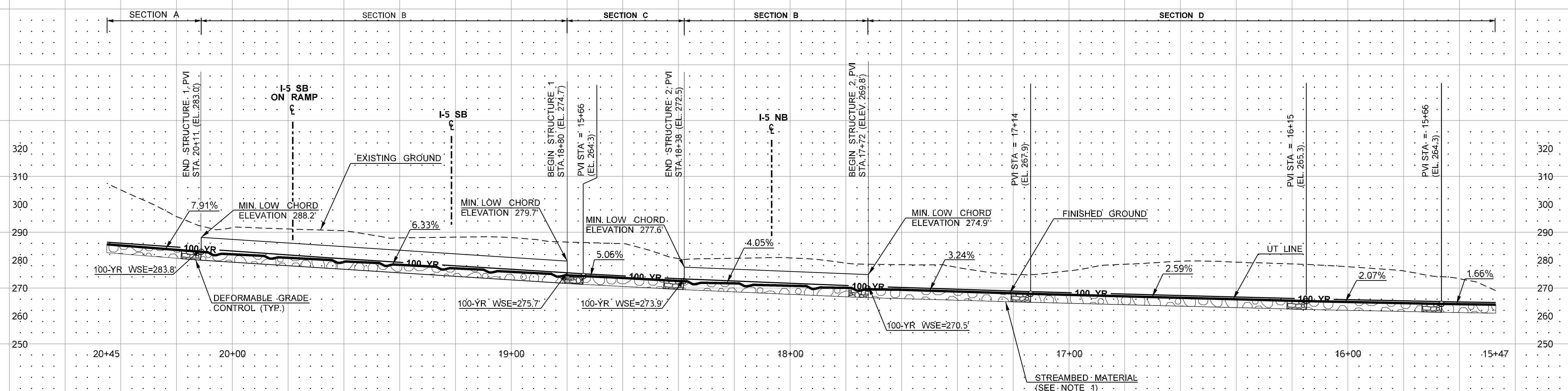
Washington State Department of Transportation

I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY TO FRIDAY CREEK

STREAM PROFILE

PLAN REF. NO. CP1

SHEET 8 OF 13 SHEETS



UT LINE PROFILE

MATCH LINE STA.20+45

STREAMBED SEDIMENT = X TONS

8 IN. STREAMBED COBBLES = X TONS

CHANNEL EXCAVATION INCL. HAUL = X CY	ONE-MAN AND TWO-MAN STREAMBED BOULDERS = X TONS STRUCTURE EXCAVATION CLASS A INCL. HAUL X CY	CHANNEL EXCAVATION INCL. HAUL = X CY LWM TYPE A = 2 LWM TYPE B = 2 LWM TYPE C = 6	ONE-MAN AND TWO-MAN STREAMBED BOULDERS = X TONS STRUCTURE EXCAVATION CLASS A INCL. HAUL X CY	CHANNEL EXCAVATION INCL. HAUL = X CY LWM TYPE A = 14 LWM TYPE B = 12 LWM TYPE C = 24

MATCH LINE STA. 15+47

NOTES:

1. SEE SPECIAL PROVISION "AGGREGRATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND COARSE BANDS. FINAL INSTALLATION WILL PROVIDE A WELL GRADED MIX OF STREAMBED SEDIMENTS AND STREAMBED COBBLES.
2. FOR STRUCTURE DETAILS SEE SHEETS 12-13.
3. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
4. EXACT STRUCTURE TYPE, SIZE, LOCATION AND WALLS TO BE DETERMINED.

DATUM (NAVD) 88

PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	$FILE$
TIME	4:38:50 PM
DATE	6/16/2022
PLOTTED BY	Teddy.Thorson
DESIGNED BY	D. STEWART
ENTERED BY	J. WILKES
CHECKED BY	N. POSEY
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

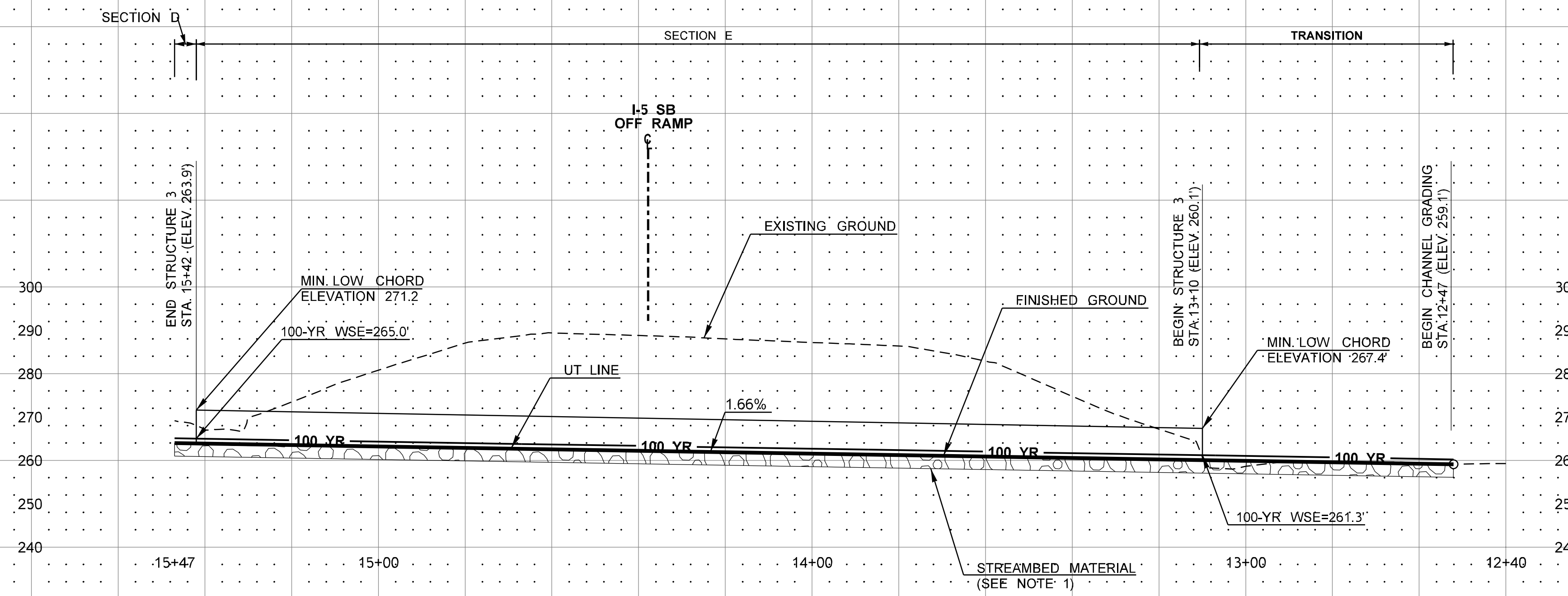
Washington State Department of Transportation

I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY TO FRIDAY CREEK

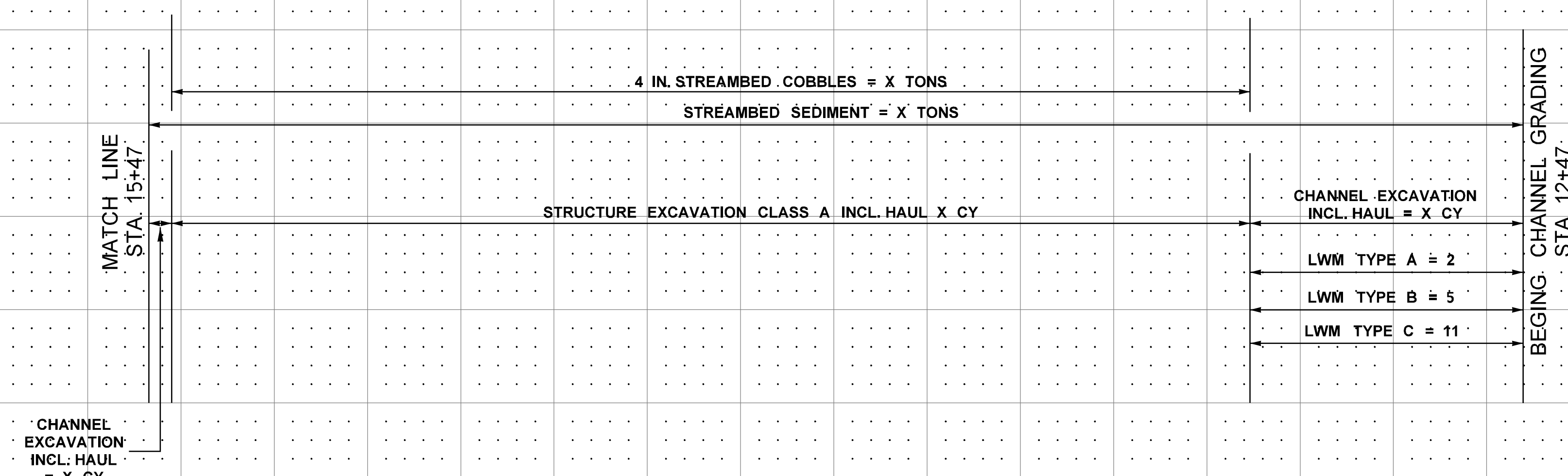
STREAM PROFILE

PLAN REF. NO. CP2

SHEET 9 OF 13 SHEETS



UT LINE PROFILE



NOTES:

1. SEE SPECIAL PROVISION "AGGREGRATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND COARSE BANDS. FINAL INSTALLATION WILL PROVIDE A WELL GRADED MIX OF STREAMBED SEDIMENTS AND STREAMBED COBBLES.
2. FOR STRUCTURE DETAILS SEE SHEETS 12-13.
3. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
4. EXACT STRUCTURE TYPE, SIZE, LOCATION AND WALLS TO BE DETERMINED.

DATUM (NAVD) 88

PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	K:\Project\33100\33178B\CADD\MicroStation\995236\CAD\ContractPlans_Alt\160-DrainProf\995236_PR_DRHY_001.dgn
TIME	4:40:02 PM
DATE	6/16/2022
PLOTTED BY	Teddy.Thorson
DESIGNED BY	D. STEWART
ENTERED BY	J. WILKES
CHECKED BY	N. POSEY
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX DATE | P.E. STAMP BOX DATE

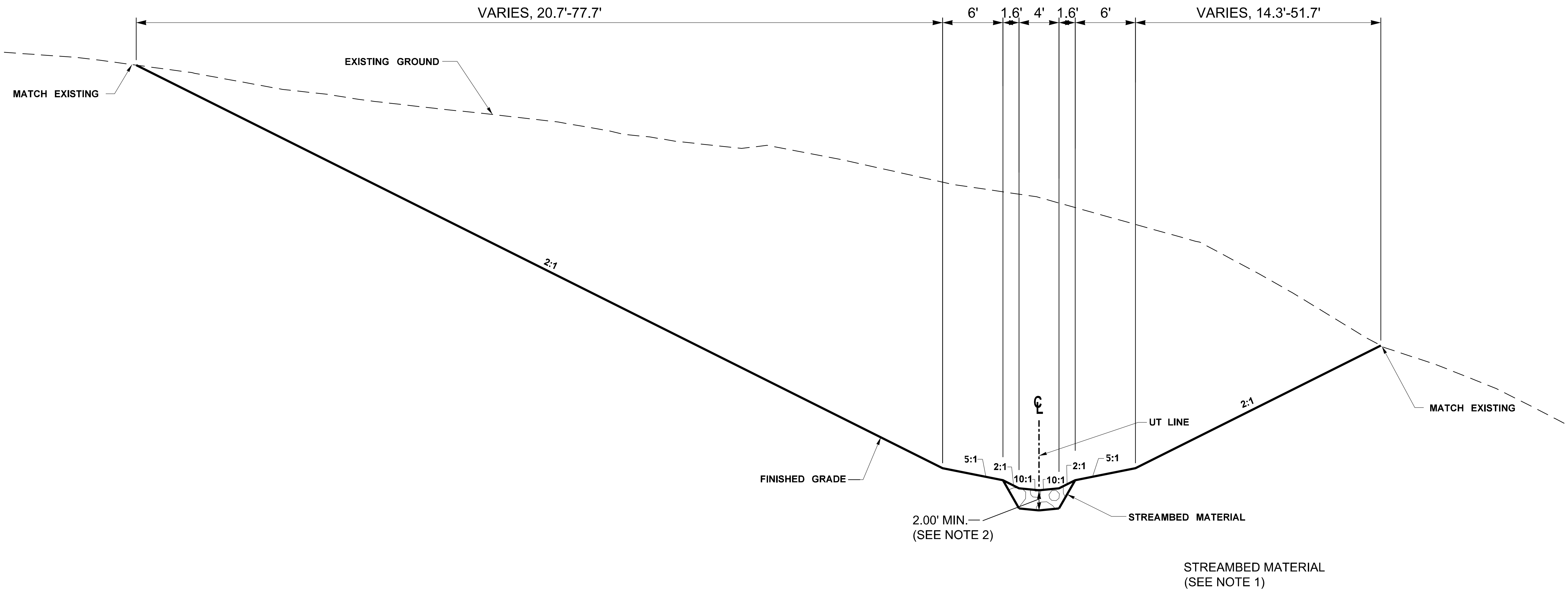
Washington State Department of Transportation

I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY TO FRIDAY CREEK

STREAM PROFILE

PLAN REF. NO. CP3

SHEET 10 OF 13 SHEETS



SECTION A

STATION
UT 20+11 TO 24+45

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATER BODIES" FOR STREAM BED AND MATERIAL LIFTS.

2. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.

3. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.

4. FROM STATION 24+60 TO 24+20, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.

FILE NAME	$FILE$
TIME	3:21:25 PM
DATE	6/13/2022
PLOTTED BY	Teddy.Thorson
DESIGNED BY	D. STEWART
ENTERED BY	J. WILKES
CHECKED BY	N. POSEY
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

Washington State
Department of Transportation

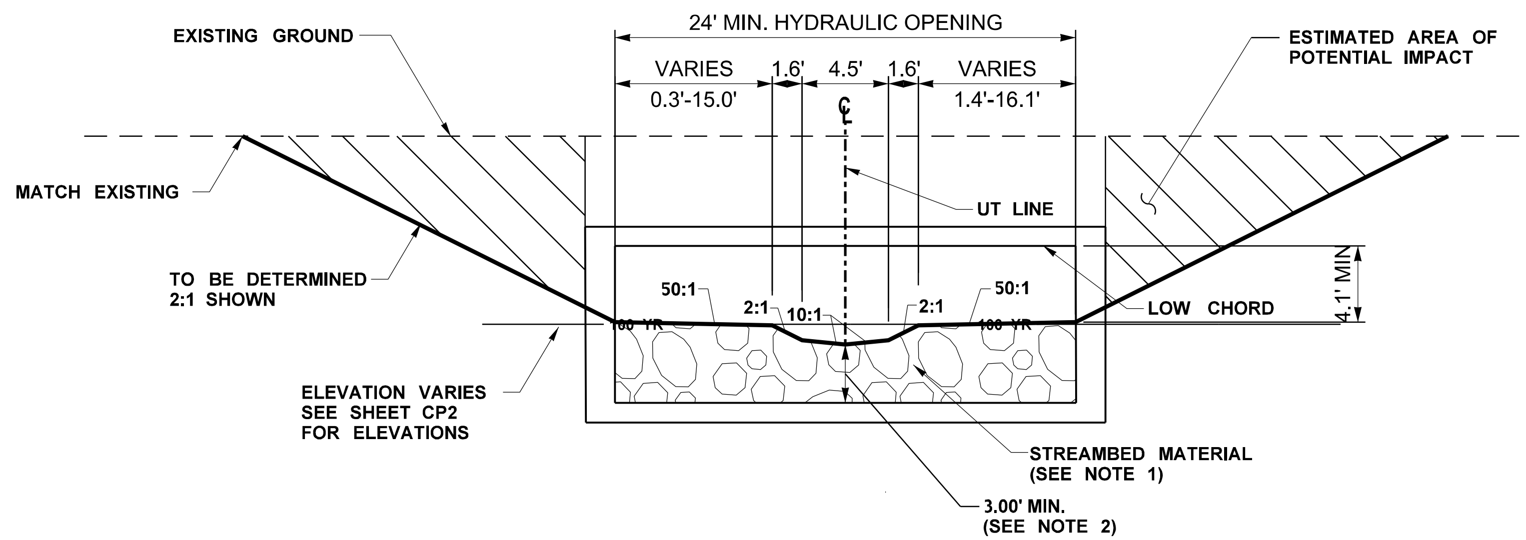
I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY TO
FRIDAY CREEK

STREAM DETAILS

PLAN REF NO
CD1

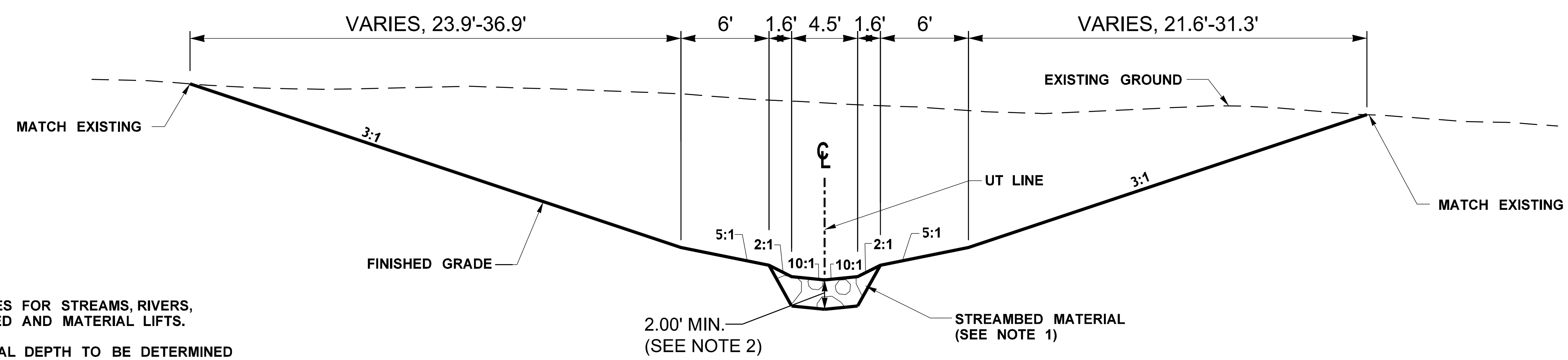
SHEET
11
OF
13
SHEETS

I-5 SB AND I-5 NB



SECTION B

STATION UT 17+72 TO 18+38
AND
UT 18+80 TO 20+11



SECTION C

STATION
UT 18+38 TO 18+80

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATER BODIES" FOR STREAM BED AND MATERIAL LIFTS.
2. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
3. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.

FILE NAME	$FILE$
TIME	3:22:35 PM
DATE	6/13/2022
PLOTTED BY	Teddy.Thorson
DESIGNED BY	D. STEWART
ENTERED BY	J. WILKES
CHECKED BY	N. POSEY
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.
JOB NUMBER
CONTRACT NO. | LOCATION NO.

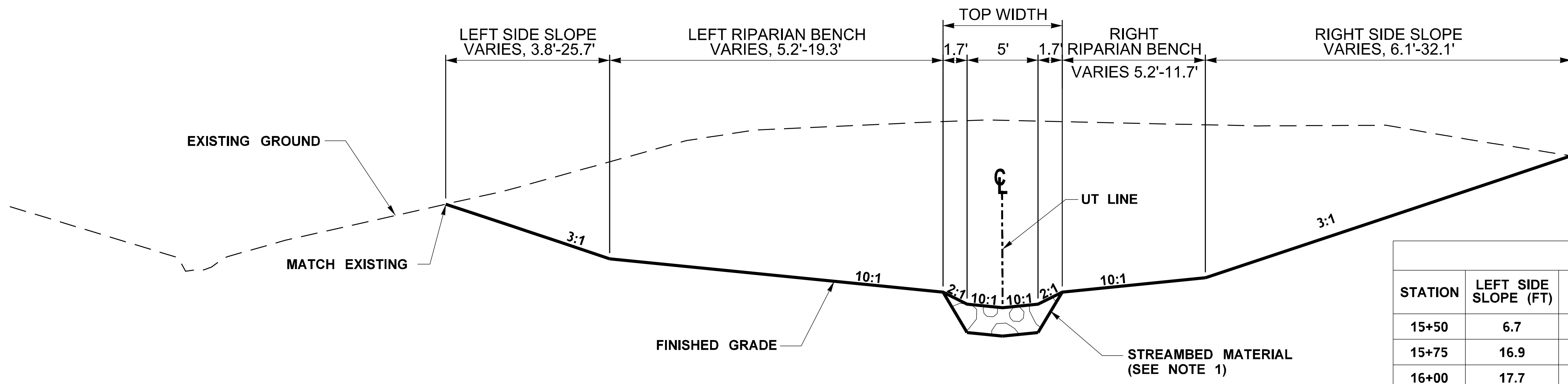
P.E. STAMP BOX DATE
P.E. STAMP BOX DATE

Washington State Department of Transportation

I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY TO FRIDAY CREEK

STREAM DETAILS

PLAN REF NO CD2
SHEET 12 OF 13 SHEETS

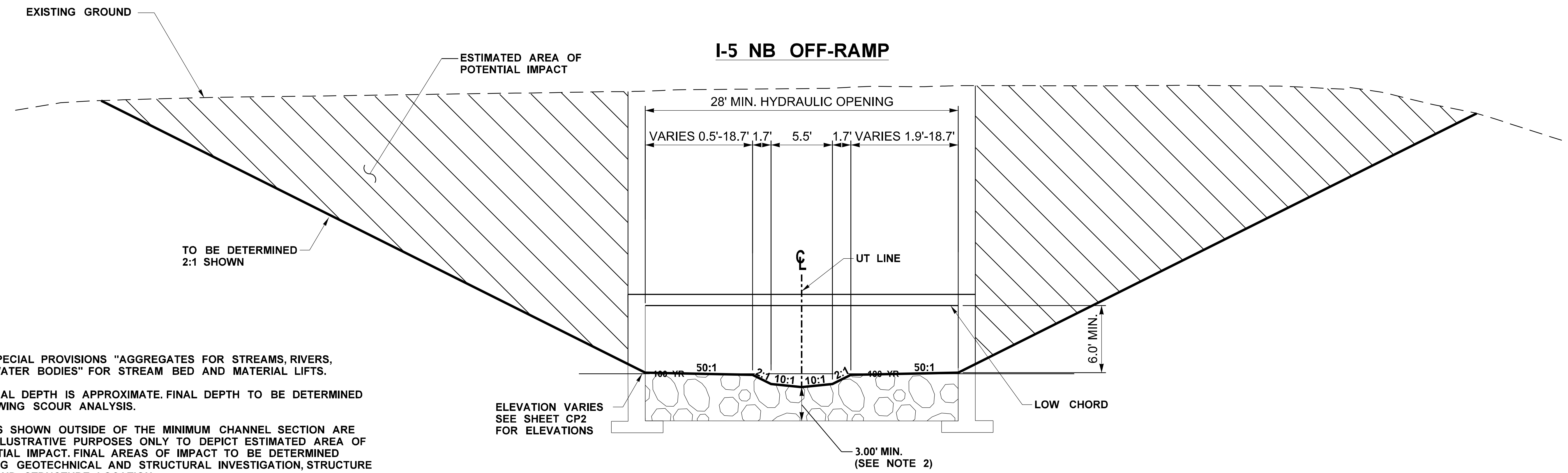


SECTION D

STATION
UT 15+42 TO 17+72

SECTION D GRADING WIDTHS					
STATION	LEFT SIDE SLOPE (FT)	LEFT RIPARIAN BENCH (FT)	TOP WIDTH (FT)	RIGHT RIPARIAN BENCH (FT)	RIGHT SIDE SLOPE (FT)
15+50	6.7	9.8	8.4	9.8	7.4
15+75	16.9	14.3	8.4	9.8	18.5
16+00	17.7	18.4	8.4	10.0	31.6
16+25	16.8	19.2	8.4	9.2	27.8
16+50	15.8	17	8.4	7.6	27.8
16+75	14.7	11.4	8.4	5.5	28.9
17+00	7.4	5.5	8.4	9.2	27.2
17+25	4.1	6.8	8.4	11.6	28.9
17+50	15.1	7.7	8.4	10.7	27.5

I-5 NB OFF-RAMP



SECTION E

STATION
UT 13+10 TO 15+42

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATER BODIES" FOR STREAM BED AND MATERIAL LIFTS.
2. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
3. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.
4. FROM STATION 13+11 TO 12+52, EVENLY TAPER SECTION E TO MATCH EXISTING CHANNEL.

FILE NAME	$FILE$
TIME	4:48:08 PM
DATE	6/16/2022
PLOTTED BY	Teddy.Thorson
DESIGNED BY	D. STEWART
ENTERED BY	J. WILKES
CHECKED BY	N. POSEY
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	

JOB NUMBER

CONTRACT NO. | LOCATION NO.

DATE
P.E. STAMP BOX

DATE
P.E. STAMP BOX

Washington State
Department of Transportation

I-5 MP 240.92 AND 240.95
SOUTH UNNAMED TRIBUTARY TO
FRIDAY CREEK

STREAM DETAILS

PLAN REF NO
CD3

SHEET
13
OF
13
SHEETS

Appendix F: Scour Calculations

Not Applicable – to be completed in Final Design.

Appendix G: Manning's Calculations

Table G-1. Summary of Manning's n Roughness coefficients for Existing Condition.

Land Cover Type	Manning's n	Reference
Existing Upstream Reach	0.11	Stream Channel Flow Resistance Coefficient Computation Tool (Version 1.1,2-2018)
Existing Middle Channel	0.035	WSDOT Figure 4A-2 (2019)
Existing Downstream Channel -	0.035	WSDOT Figure 4A-2 (2019)
Floodplain - Light Brush and Trees, in Summer	0.08	WSDOT Figure 4A-2 (2019)
Floodplain - Medium to dense Brush and Trees, in Summer	0.16	WSDOT Figure 4A-2 (2019)
Asphalt Pavement-	0.016	SRH-2D Manual (FHWA, 2019)

	Manning's value adjustemnets	Base	Degree of irregularity	Variation in channel cross section	Effect of obstruction	Amount of Vegetation	Degree of meandering	Manning's roughness coefficient
Existing Channel	Upstream	0.05	0	0	0.005	0.03	1	0.085
	Middle	0.035	0	0	0	0	1	0.035
	Downstream	0.035	0	0	0.007	0.01	1	0.052

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name:	South Tributary		**Reach:**	Upstream Existing Reach
Stream Slope, *S* (ft/ft):	0.08100		**Date:**	9/1/2021
			Practitioner:	S. Mardani / D. Stewart

Reach D_{50}, D_{84} (mm):	18.2	48.6	**Step D_{84} (mm)[a]:**	90
Hydraulic Radius, *R* (ft):	0.90			
Mean Flow Depth, *d* (ft)[b]:	1.63			
Bedform Variation, σ_z (ft)[c]:	0.49			
Median Thalweg Depth, h_m (ft)[c]:	1.63			
Large Wood in Steps? (y/n)[c]:	y			

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 ft/ft (see sheet "S>0.03, Sigma z")

1 **Consult Tabular Guidance** → 2 **Consult Photographic Guidance** → 3 **Apply a Quantitative Prediction Method**

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's *n* , Darcy-Weisbach *f*) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

	n	*f*	Use in Average? Enter "y"
Tabular Estimate:	0.050	0.302	y
Estimate from Photographic Guidance:	0.130	2.043	y

Instructions: (See technical summary report, TS-103, for more detailed instructions and references.)

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
(3) Consult tabular guidance and enter the best estimate in the grey box (cell I43; do not use in average if not confident of estimate). Tabular values are typically substantially underestimated for channels > ~3% slope.
(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: South Tributary
Slope, *S* (ft/ft): 0.08100
Reach: Upstream Existing Reach
Date: 9/1/2021
Practitioner: S. Mardani / D. Stewart

D_{50}, D_{84}, $D_{84,\ step}$ (m):	0.02	0.05	0.09
R (ft, m):	0.90	0.27	
d (ft^2, m^2):	1.63	0.50	
σ_z (ft, m):	0.49	0.15	
h_m (ft, m):	1.63	0.50	

Overall Average n:	0.111
f:	1.913
Quantitative Average n (1):	0.179
f (1):	4.433
Arcement and Schneider (1989) n:	0.085
f:	0.873

3 Quantitative Prediction

Quasi-Quantitative:

	n_b (2)	n_1	n_2	n_3	n_4	m	**Estimate**	**Use in Average? Enter "y"**
Arcement and Schneider (1989) $n = (n_b + n_1 + n_2 + n_3 + n_4)m$	0.05	0	0	0.005	0.03	1	0.085	y
	Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	**Relative Submergence (3)**	**Estimate n**	**Estimate f**	**# Data Points**	**Applicable Range Slope (ft/ft)**	**Applicable Range Relative Sub. (3)**	**Use in Average? Enter "y"**
Yochum et al. (2012) [R^2 = 0.78; f: R^2 = 0.82]	3.3	0.179	4.43	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	y
Rickenmann and Recking (2011)	10.22	----	----	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	
Aberle and Smart (2003); in flume	3.3	0.085	0.87	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002) (4) [RMS error = 19%]	3.04	----	----	81	0.027 to 0.184	R/D_{84} (step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	10.22	----	----	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	
Jarrett (1984) [ave. std. error = 28%]	n/a	----	----	75	0.002 to 0.039	n/a	
Griffiths (1981); rigid bed [R^2=0.59]	15.0	----	----	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	
Hey (1979); a = 12.72	5.6	----	----	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	
Limerinos (1970) [R^2=0.77]	5.6	----	----	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	

Notes:
(1) Quantitative average excludes the Arcement and Schneider (1989) method.
(2) In some situations it can be appropraite to assume that the quantitative average n is n_b., though this may result in overestimated flow resistance.
(3) Relative submergence is computed using either *R* (hydraulic radius) or d (mean depth) and the D_{50} (median bed material size) or D_{84} (84% of bed material smaller); or computed using either h_m (median thalweg depth) or *d* and σ_z (standard deviation of residuals of a thalweg longitudinal profile regression). For σ_z computation, see "S>0.03, Sigma z" tab of this spreadsheet.
(4) This method can substantially underestimate flow resistance in steeper streams (slope>0.03) where large wood is present

Table G-2. Summary of Manning's n Roughness coefficients for Proposed Conditions.

Land Cover Type	Manning's n	Reference	Reference
Upstream Project Reach, including large wood Slope=6-8%	0.085	WSDOT Figure 4A-2 (2019), Arcement and Schneider (1989)	WSDOT Figure 4A-2 (2019), Arcement and Schneider (1989)
Project Reach Channel, including large wood, Slopes 3-6%	0.080	WSDOT Figure 4A-2 (2019), Arcement and Schneider (1989)	WSDOT Figure 4A-2 (2019), Arcement and Schneider (1989)
Project Reach Channel, including large wood, Slopes less than 3%	0.075	WSDOT Figure 4A-2 (2019), Arcement and Schneider (1989)	WSDOT Figure 4A-2 (2019), Arcement and Schneider (1989)
Crossing Structure, with step-pools, Slope of 6-7%	0.065	WSDOT Figure 4A-2 (2019), Arcement and Schneider (1989)	WSDOT Figure 4A-2 (2019), Arcement and Schneider (1989)
Crossing Structure, with step-pools, Slope of 3-4%	0.060	WSDOT Figure 4A-2 (2019), Arcement and Schneider (1989)	WSDOT Figure 4A-2 (2019), Arcement and Schneider (1989)
Crossing Structure, with meander bars, Slope of 1.7%	0.045	WSDOT Figure 4A-2 (2019), Arcement and Schneider (1989)	WSDOT Figure 4A-2 (2019), Arcement and Schneider (1989)

	Manning's value adjustemnets	Base	Degree of irregularity	Variation in channel cross section	Effect of obstruction	Amount of Vegetation	Degree of meandering	Manning's roughness coefficient
Proposed Channel	Upstream Project Reach, including large wood Slope=8.1%	0.05	0	0	0.025	0.01	1	0.085
	Crossing Structure, with step-pools, Slope of 6-7%	0.05	0.005	0	0.01	0	1	0.065
	Project Reach Channel, including large wood, Slope=3-6%	0.045	0	0	0.025	0.01	1	0.080
	Crossing Structure, with step-pools, Slope of 3-4%	0.04	0.005	0	0.015	0	1	0.060
	Crossing Structure, with meander bars, Slope of 1.7%	0.035	0.005	0	0.005	0	1	0.045
	Downstream Reach Channel, including large wood, Slope=1.7%	0.035	0	0	0.03	0.01	1	0.075

MANNING'S N CALCULATIONS

Project:	South Tributary to Friday Creek		
SR Route:	I-5	**Mile Post:**	240.92
Stream Crossing:	South Tributary - Proposed Reach A		
Designer:	T. Thorson, Otak	**Date:**	3/23/2022
Checked By:	D. Stewart, Otak		

References:

Jarrett, R.D. (1984) Hydraulics of High-Gradient Streams, ASCE Journal Hydraulics Division, v.110, p.1519-1539.

Bathurst, J.C. (1985) Flow Resistance Estimation in Mountain Rivers, ASCE Journal of Hydraulic Eng, v.111, p.625-641

Mussetter, R.A. (1989) Dynamics of Mountain Streams, PhD Dissertation, Colorado State Uniersity, 206 pp.

Smart, G.M. and Jaeggi, M.N.R. (1983) Sediment Transport on Steep Slopes.

Coon, William F. (1998) Estimation of Roughness Coefficients for Natural Stream Channels with Vegetated Banks, p.5

Input Data From HEC-RAS

Cross Section Name/Station:		**Proposed Reach A**	
Flow Event:		100	yr
Hydraulic Radius (R) - ft:	R =	*0.592*	ft
Hydraulic Depth (D) - ft:	D =	*1.020*	ft
Energy Slope (S) - ft/ft:	S =	*0.079*	ft/ft
D_{90} - ft:	D_{90} =	*0.245*	ft
D_{84} - ft:	D_{84} =	*0.181*	ft
D_{50} - ft:	D_{50} =	*0.071*	ft
Relative Submergence:	$\frac{R}{D_{84}}$=	3.268	ft/ft

Jarret

Applicability

Slope:	0.2 - 5.2%
Hydraulic Radius:	0.5 - 7.2 ft
d/D_{84}:	0.4 - 11.2
D_{50}:	61 - 427 mm (0.2 - 1.4 ft)

Constant: $C = 1.486 \frac{ft^{2/3}}{s}$

$$n = \frac{C * R^{\frac{1}{6}}}{g^{0.5} * 0.671 * R^{\frac{1}{3}} * S^{-0.38}}$$

Not Applicable

n = 0.162

Bathurst

Applicability

Slope:	0.4 - 3.7%
R/D_{84}:	0.43 - 11.4
D_{84}:	113 - 740 mm (0.4 - 2.4ft)
D_{50}:	60 - 343 mm (0.2 - 1.1ft)

Constant: $C_u = 1.486 \frac{ft^{1/3}}{s}$

$$n = \frac{C_u * R^{\frac{1}{6}}}{g^{0.5} * \left(4 + 5.62 \log\left(\frac{D}{D_{84}}\right)\right)}$$

Not Applicable

n = 0.029

Mussetter

Applicability

Slope:	0.6 - 18.2%
d/D_{84}:	0.15 - 3.7
D_{84}:	85 - 1250 mm (0.3 - 4.1ft)
D_{50}:	35 - 640 mm (0.1 - 2.1ft)
Drainage Area	0.14 - 3.72 mi^2

Constant: $C_u = 1.486 \frac{ft^{1/3}}{s}$

$$n = \frac{C_u * R^{\frac{1}{6}}}{g^{0.5} * \left[1.11 * \left(\frac{D}{D_{84}}\right)^{0.46} * \left(\frac{D_{84}}{D_{50}}\right)^{-0.85} * S^{-0.39}\right]}$$

n = 0.080

Smart and Jaeggi

Applicability

Slope: Up to 20%

Constant: $C = 0.26194 ft^{\frac{-1}{6}}$

$$n = \frac{C * R^{\frac{1}{6}}}{\left[5.75 * \left[1 - e^{\left[-0.05 * \frac{R}{D_{90}} * \frac{1}{S^{0.5}}\right]}\right]^{0.5} * \log\left(8.2 * \frac{R}{D_{90}}\right)\right]}$$

n = 0.054

Limerinos

Applicability

Slope:	less than 0.2%
Hydraulic Radius:	less than 11ft
D_{50}:	0.02 - 0.83ft
Note:	appropriate for high within-bank flows in gravel-bed channels with small bed-material transport and insignificant channel bed vegetation.

$$n = \frac{(0.0926) * R^{\frac{1}{6}}}{\left(1.16 + 2.0 * \log\left(\frac{R}{D_{84}}\right)\right)}$$

Not Applicable

$\boxed{n = 0.039}$

Washington State Department of Transportation

MANNING'S N CALCULATIONS

Project:	South Tributary to Friday Creek		
SR Route:	I-5	**Mile Post:**	240.92
Stream Crossing:	South Tributary - Proposed Reach B		
Designer:	T. Thorson, Otak	**Date:**	3/23/2022
Checked By:	D. Stewart, Otak		

References:

Jarrett, R.D. (1984) Hydraulics of High-Gradient Streams, ASCE Journal Hydraulics Division, v.110, p.1519-1539.

Bathurst, J.C. (1985) Flow Resistance Estimation in Mountain Rivers, ASCE Journal of Hydraulic Eng, v.111, p.625-641

Mussetter, R.A. (1989) Dynamics of Mountain Streams, PhD Dissertation, Colorado State Uniersity, 206 pp.

Smart, G.M. and Jaeggi, M.N.R. (1983) Sediment Transport on Steep Slopes.

Coon, William F. (1998) Estimation of Roughness Coefficients for Natural Stream Channels with Vegetated Banks, p.5

Input Data From HEC-RAS

Cross Section Name/Station:		Proposed Reach B	
Flow Event:		100	yr
Hydraulic Radius (R) - ft:	R =	*0.485*	ft
Hydraulic Depth (D) - ft:	D =	*1.030*	ft
Energy Slope (S) - ft/ft:	S =	*0.032*	ft/ft
D_{90} - ft:	D_{90} =	*0.118*	ft
D_{84} - ft:	D_{84} =	*0.093*	ft
D_{50} - ft:	D_{50} =	*0.037*	ft
Relative Submergence:	$\frac{R}{D_{84}}$=	5.215	ft/ft

Jarret

Applicability

Slope:	0.2 - 5.2%
Hydraulic Radius:	0.5 - 7.2 ft
d/D_{84}:	0.4 - 11.2
D_{50}:	61 - 427 mm (0.2 - 1.4 ft)

Constant: $C = 1.486 \frac{ft^{2/3}}{s}$

$$n = \frac{C * R^{\frac{1}{6}}}{g^{0.5} * 0.671 * R^{\frac{1}{3}} * S^{-0.38}}$$

$\boxed{n = 0.120}$

Bathurst

Applicability

Slope: 0.4 - 3.7%

R/D_{84}: 0.43 - 11.4

D_{84}: 113 - 740 mm (0.4 - 2.4ft)

D_{50}: 60 - 343 mm (0.2 - 1.1ft)

Constant: $C_u = 1.486 \frac{ft^{1/3}}{s}$

$$n = \frac{C_u * R^{\frac{1}{6}}}{g^{0.5} * \left(4 + 5.62 \log\left(\frac{D}{D_{84}}\right)\right)}$$

n = 0.024

Mussetter

Applicability

Slope: 0.6 - 18.2%

d/D_{84}: 0.15 - 3.7

D_{84}: 85 - 1250 mm (0.3 - 4.1ft)

D_{50}: 35 - 640 mm (0.1 - 2.1ft)

Drainage Area 0.14 - 3.72 mi^2

Constant: $C_u = 1.486 \frac{ft^{1/3}}{s}$

$$n = \frac{C_u * R^{\frac{1}{6}}}{g^{0.5} * \left[1.11 * \left(\frac{D}{D_{84}}\right)^{0.46} * \left(\frac{D_{84}}{D_{50}}\right)^{-0.85} * S^{-0.39}\right]}$$

n = 0.040

Smart and Jaeggi

Applicability

Slope: Up to 20%

Constant: $C = 0.26194 ft^{\frac{-1}{6}}$

$$n = \frac{C * R^{\frac{1}{6}}}{\left[5.75 * \left[1 - e^{\left[-0.05 * \frac{R}{D_{90}} * \frac{1}{S^{0.5}}\right]}\right]^{0.5} * \log\left(8.2 * \frac{R}{D_{90}}\right)\right]}$$

n = 0.032

<u>Limerinos</u>

Applicability

Slope:	less than 0.2%
Hydraulic Radius:	less than 11ft
D_{50}:	0.02 - 0.83ft
Note:	appropriate for high within-bank flows in gravel-bed channels with small bed-material transport and insignificant channel bed vegetation.

$$n = \frac{(0.0926) * R^{\frac{1}{6}}}{\left(1.16 + 2.0 * \log\left(\frac{R}{D_{84}}\right)\right)}$$

Not Applicable

n = 0.032

Appendix H: Large Woody Material Calculations

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	*I-5 MP 240.92*		**Key piece volume**	*1.310*	*yd3*		
Stream name	*South Trib*		**Key piece/ft**	*0.0335*	*per ft stream*		
length of regrade[a]	*1200*	*ft*	**Total wood vol./ft**	*0.3948*	*yd3/ft stream*	Taper coeff.	-0.01554
Bankfull width	*8*	*ft*	**Total LWM**[c] **pieces/ft stream**	*0.1159*	*per ft stream*	LF_{rw}	1.5
Habitat zone[b]	*Western WA*					H_{dbh}	4.5

Log type	*Diameter at midpoint (ft)*	*Length(ft)* [d]	*Volume (yd^3/log)* [d]	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd^3)*	DBH based on mid point diameter (ft)	$D_{root\ collar\ (ft)}$	L/2-Lrw (ft)
A	1.88	*30*	3.08	**yes**	yes	40	123.37	2.00	2.07	12.18
B	1.45	*20*	1.22	**yes**	no	44	53.82	1.50	1.57	7.825
C	0.98	*15*	0.42	**yes**	no	66	27.66	1.00	1.07	6.03
D			0.00				0.00		0.00	0
E			0.00				0.00		0.00	0
F			0.00				0.00		0.00	0
G			0.00				0.00		0.00	0
H			0.00				0.00		0.00	0
I			0.00				0.00		0.00	0
J			0.00				0.00		0.00	0
K			0.00				0.00		0.00	0
L			0.00				0.00		0.00	0
M			0.00				0.00		0.00	0
N			0.00				0.00		0.00	0
O			0.00				0.00		0.00	0
P			0.00				0.00		0.00	0

	No. of key pieces	**Total No. of LWM pieces**	**Total LWM volume (yd^3)**
Design	40	150	204.9
Targets	**40**	**139**	**473.8**
	on target	surplus	deficit

[a] **includes length through crossing, regardless of structure type**

[b] **choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information**

Western Washington lowla	(generally <4,200 ft. in elevation west of the Cascade Crest)
Alpine	(generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)
Douglas fir-Ponderosa pine	(mainly east slope Cascades below 3,700 ft. elevation)

[c]**LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).**

[d]**includes rootwad if present**

Key piece volume	
BFW class (ft)	volume (yd3)
0-16	1.31
17-33	3.28
34-49	7.86
50-66	11.79
67-98	12.77
99-164	13.76
165-328	14.08

adapted from Fox and Bolton (2007), Table 5

Key Piece density lookup table		
Habitat zone	BFW class (feet)	75th percentile (yd3/ft stream)
Western WA	0-33	0.0335
	34-328	0.0122
Alpine	0-49	0.0122
	50-164	0.0030
Douglas Fir/Pond. Pine (much of eastern WA)	0-98	0.0061

adapted from Fox and Bolton (2007), Table 4

Total Wood Volume lookup table		
Habitat zone	BFW class (feet)	75th percentile (yd3/ft stream)
Western WA	0-98	0.3948
	99-328	1.2641
Alpine	0-10	0.0399
	11-164	0.1196
Douglas Fir/Pond. Pine	0-98	0.0598

adapted from Fox and Bolton (2007), Table 4

Number of LWM pieces lookup table		
Habitat zone	BFW class (feet)	75th percentile (per/ft stream)
Western WA	0-20	0.1159
	21-98	0.1921
	99-328	0.6341
Alpine	0-10	0.0854
	11-98	0.1707
	99-164	0.1921
Douglas Fir/Pond.	0-20	0.0884
	21-98	0.1067

Appendix I: Reach Assessment

Not applicable to the South Tributary to Friday Creek. No prior reach assessment has been completed for the site.

Appendix J: Climate Resiliency Calculations

Future Projections for Climate-Adapted Culvert Design

Project Name: 995236

Stream Name: Unnamed Trib to Friday Creek

Drainage Area: 82 ac

Projected mean percent change in bankfull flow:

2040s: 15.4%

2080s: 20.9%

Projected mean percent change in bankfull width:

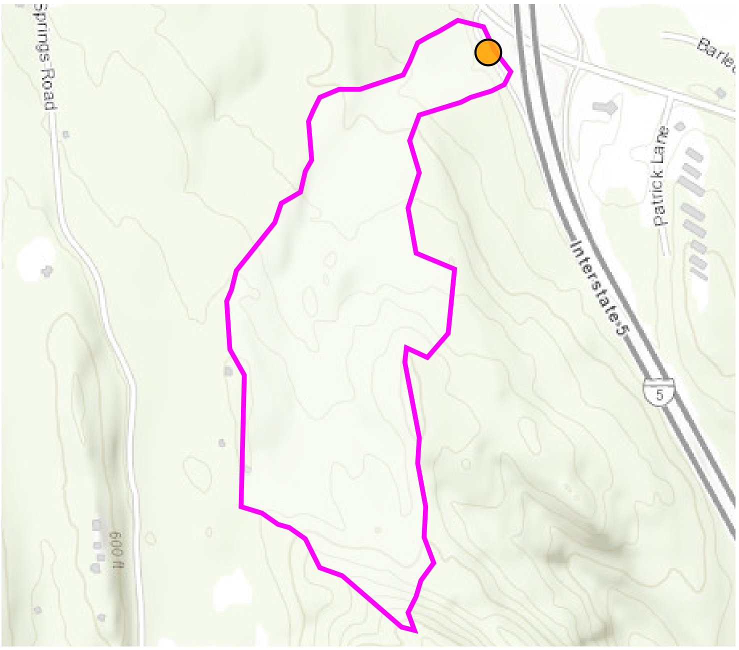
2040s: 7.4%

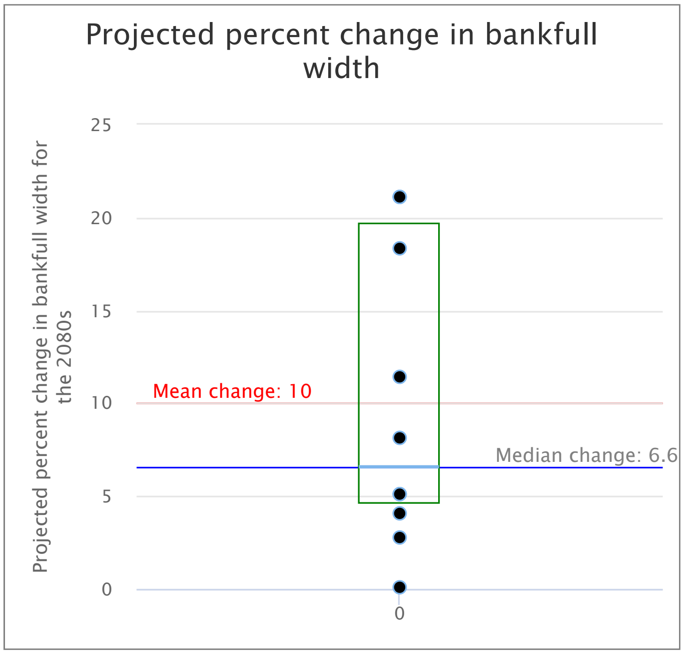
2080s: 10%

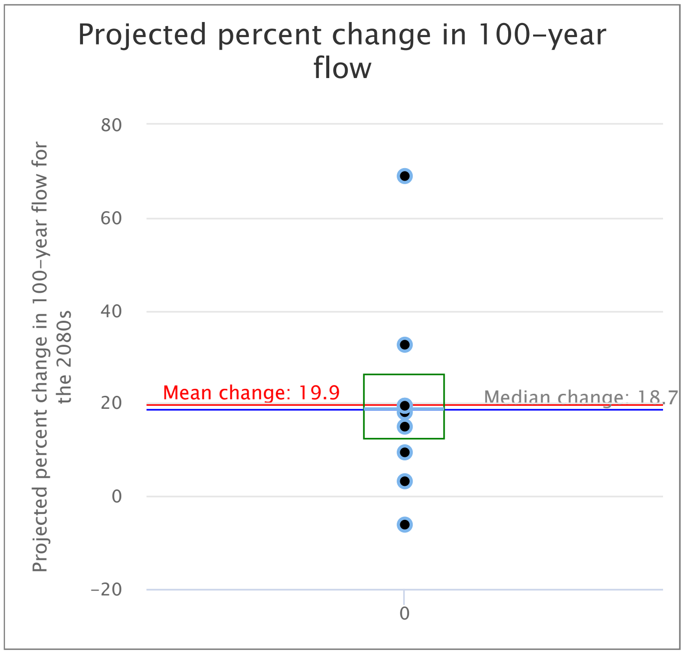
Projected mean percent change in 100-year flood:

2040s: 8.6%

2080s: 19.9%







Black dots are projections from 10 separate models